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THE USE OF ERTS IMAGERY IN RESERVOIR MANAGEMENT AND OPERATION

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16. Abstract

The New England Division, Corps of Engineers (NED) participated in the ERTS-1 experiment to assess the possible future usefulness of satellites such as ERTS in the operation of its water resources systems used to control floods.

Based on two years' experience with a 26-station network in New England, NED has found real time data collection by orbiting satellite relay to be both reliable and feasible. Orbiting satellite systems can be designed that are more flexible, easily maintained and less expensive than conventional ground-based means.

In the assessment of ERTS imagery, we have found that better spatial resolution and/or additional spectral bands would be required to satisfy NED's needs, in most cases. Also, the mass of data presented in an image is too unwieldy for timely analysis by photointerpretive techniques. A man-computer interactive system, using Cathode Ray Tube display could solve the latter problem. Real time imagery acquisition on an every day or every other day basis would be essential in a fully operational environment.

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PREFACE

The New England Division, Corps of Engineers (NED) participated in the Earth Resources Technology Satellite, ERTS-1 experiment to assess the possible future usefulness of satellites such as ERTS in the operation of its water resources systems used to control floods. The Data Collection and imaging systems have been studied, both as separate entities and for potential coordinated application to operational needs.

Based on two years' experience with a 26-station network in New England, NED has found real time data collection by orbiting satellite relay to be both reliable and feasible. Orbiting satellite systems can be designed that are more flexible, easily maintained and less expensive than conventional ground-based means. The only drawback with the ERTS-1 Data Collection System (DCS) for NED operational purposes is the frequency of data reports (four to six times daily). However, it should be understood that the ERTS system is experimental, to test the feasibility of data collection by orbiting satellite. An operational system could be designed involving more than one satellite, to increase the frequency of data reporting.

Based on its ERTS-1 experience, NED endorses the institution of a satellite data collection system on a Corps-wide basis or a nationwide system with other Federal and State agencies, whether it be of the orbiting type with which we have experimented, or the geostationary kind, for which evaluation is not yet available. Any operational satellite configuration should include ground receive stations at all major user locales for direct receipt of satellite information, rather than the present relay of data from NASA. Therefore NED, with NASA support, is constructing an inexpensive, semiautomatic and easily maintained ground receive station as a follow-up to its present investigation. This is expected to further demonstrate the utility of satellite data relay by testing a system in a quasi-operational mode.

Using standard photo equipment, experience in this investigation has indicated that ERTS photo imagery may be enlarged about five times, or to a scale of 1:200,000. This is sufficient for only rather large scale or gross feature patterns to be represented.

Depiction of floods is restricted to gross overflow of waters from the larger rivers in New England and this is only very marginally useful for reservoir regulation purposes. Ice is readily detectable on the ERTS imagery as is the ice-open water interface. This could be useful, especially over remote areas, for monitoring developing ice jams. Indications of varying water quality characteristics are recognizable in ERTS imagery, however so many different parameters are involved in water quality, and in such varying degrees, often intermingled with each other that much study still remains before ERTS imagery could relate specific spectral responses to specific ground truth information. Winter snow cover patterns are readily obtainable with excellent accuracy from ERTS imagery, however the imagery provides only snow location, not water equivalent which is the operationally important parameter. Finally, ERTS imagery appears able to distinguish areas previously, but no longer flooded, for periods up to at least several months after flood recession. Whether this is a soil moisture or a vegetation-related phenomenon is open to further study. The diazo process of producing contact acetate color composites of ERTS scenes was frequently used in the photo-interpretation portion of this ERTS investigation. It was found to be quite useful in that the composite product of several bands allows one image to represent the information that would otherwise have to be obtained from each of the constituent bands separately.

It is recommended in this report that additional bandwidths, especially those in the ultraviolet and thermal infrared be considered for future satellites to help solve some of the unresolved problems of quantifying certain feature characteristics on the imagery such as snow water content, water depth and water quality.

The ERTS Computer Compatible Tapes (CCT's) provide data in digital form thus allowing high speed processing of the imagery information. This can be important since for most operational applications the mass of data in an ERTS image may tend to be too unwieldy for timely analysis by photo interpretive techniques. Computer processing provides the means of quantifying scene radiance values over elemental areas, and thus the CCT printout imagery, composed of alphanumeric symbols spaced on a rectangular format, also allows better feature representation at a larger scale than would an enlargement of a photo to the same scale. The minimum possible width of a river that should theoretically always be detectable as water is equal to 2 pixel lengths or 374 feet

(crosstrack) or 500 feet (in-track). The minimum possible areal size of a water body (pond) that would be always detectable as water = 187,000 feet^2 or 4.3 acres. A study of surface water characteristics at a small pond (7 acres) in Connecticut yielded an actual correlation between imagery reflectance and presence of surface water of 0.974 and between reflectance and water depth of 0.949. While the relationship between reflectance and presence of surface water can undoubtedly be extended to all surface waters, that between reflectance and depth probably cannot, since detection of depth variations is in turn dependent on such variable factors as turbidity and other water quality parameters, as well as bottom reflectance, etc. The particular case studied here nevertheless provides hope that in certain waters, ERTS can detect differences in depth, however further study is needed to determine if and how this could be extended to the general case.

Work has been accomplished in the development of a man/computer interactive system, with a Cathode Ray Tube (CRT) and light pen, that could allow real time analysis and utilization of ERTS computer imagery for important water resource management decisions. As part of our ERTS-B follow-on investigation, we hope to continue development of this system which could maintain as a data base information obtained from many MSS tapes, then use this information to predict occurrences similar to those stored, upon input of image information on a real time basis in an operational situation.

In general the 18-day ERTS coverage is inadequate for the operational needs of the NED Reservoir Control Center. However an every day or every other day coverage would be significantly useful during high flood potential periods.

Factors which degrade the spatial, temporal or spectral resolution of ERTS imagery are of extreme importance to NED operations. Any degradation of the interpreted product, for whatever reason can severely reduce the usefulness of the imagery for NED reservoir control purposes. For example, interpretation of ERTS imagery has been compromised by weather factors such as cloud cover, haze and atmospheric attenuation caused by light scattering.

For NED operational purposes, an all-weather and day-night capability would greatly enhance the usefulness of the ERTS imagery. Major decisions are made during flood situations which occur during inclement weather and many times at night. Restriction of

imagery capabilities to clear weather daylight hours imposes severe difficulties for NED operational missions. Consideration should be given to the use of thermal infrared bands as well as radar in attempting to answer these needs.

NED has concluded that the coordinated use of all data available to a real time operational Reservoir Control Center should include the interaction between real time imagery and point data sources, such as the ERTS DCS for ground truth. Before this interaction situation can become a reality it would be necessary to provide some means of real time relay of ERTS imagery to an operational Control Center.

Since the technological feasibility of the use of satellites has been demonstrated by ERTS, the next stage of system development should be initiated; namely, pilot project test and evaluation demonstrations under quasi-operational conditions. The NED LANDSAT-2 follow-on experiment will address this subject as will also a cooperative demonstration study with NASA of a user-operated ground receive station for direct acquisition of DCS data.

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1.0 INTRODUCTION

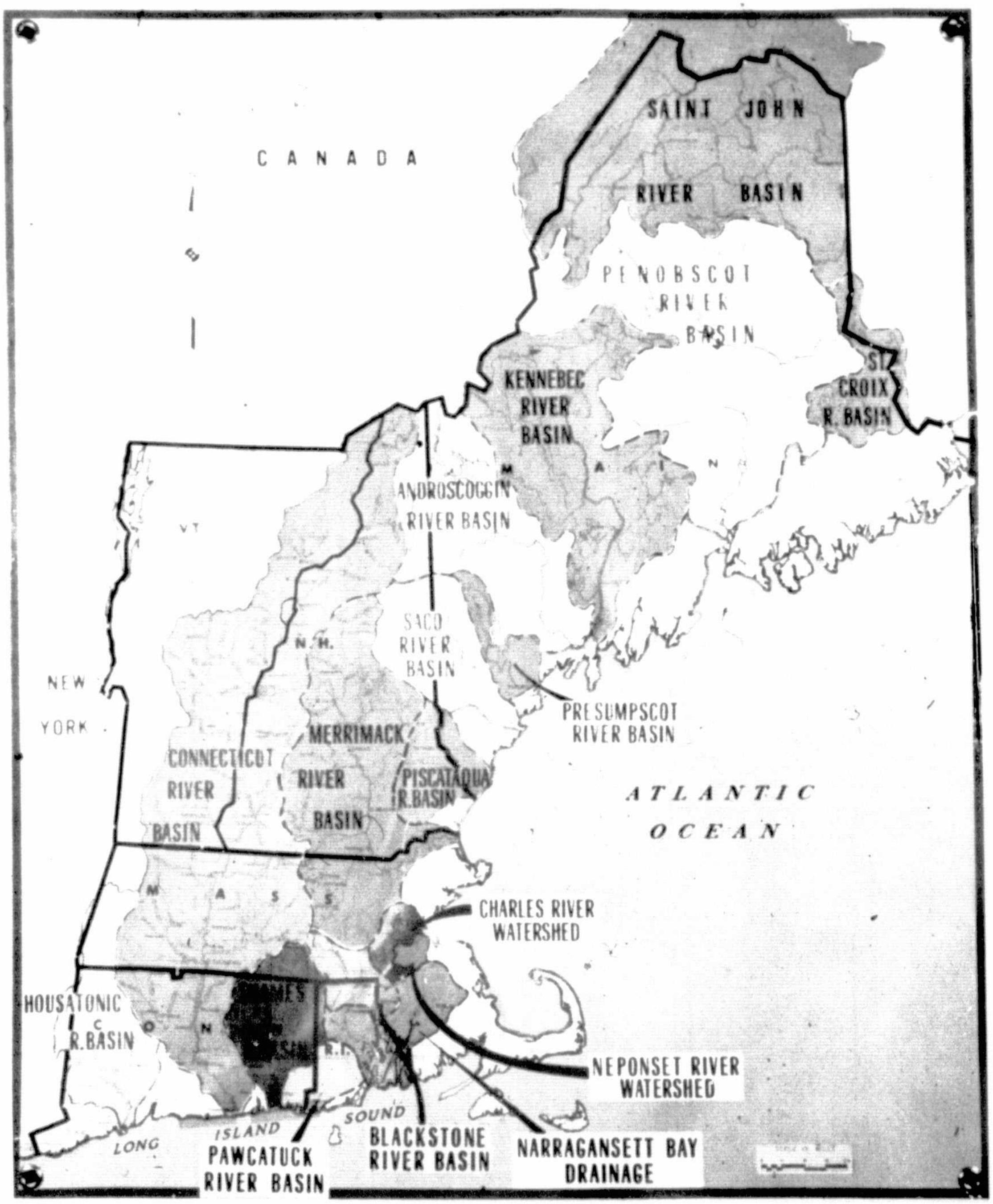
The New England Division (NED), Corps of Engineers has experimented with the Earth Resources Technology Satellite (ERTS-1) Data Collection and Imaging Systems for more than two years, following the launch of the satellite in July 1972. The purpose of this experiment has been to evaluate the future usefulness of data products received from satellites such as ERTS in the day-to-day operation of the NED water resources systems used to control floods.

2.0 BACKGROUND

The New England region, shown on figure 1, is comprised of a number of watersheds, draining hilly terrain. The NED area of responsibility covers all of Maine, New Hampshire and Vermont to the western limits of the Connecticut River basin, Massachusetts, Connecticut to the western edge of the Housatonic River basin and Rhode Island. Most of the population in New England lives in the southern and central regions. With the high degree of development that has taken place along the rivers and coastal locations have come the perennial problems of flood damage and flood protection. The Corps of Engineers has expended over $300 million for a flood control system consisting of 35 reservoirs, 37 local protection projects and 4 hurricane barriers. The flood control plan in each river basin consists of upstream reservoirs and dikes and floodwalls at the principal damage centers. All reservoirs have storage allocated for flood control and many have storage for other uses such as recreation, water supply and conservation. NED reservoirs presently have no storage for power, irrigation or navigation.

The New England Division also is responsible for providing such flood prevention aids as engineering reports on streams, shores and flood plains, flood insurance studies and flood plain management services. National disaster recovery and restoration work is a continuing responsibility of the Corps. The Division also improves harbors and navigation channels and administers laws relating to the preservation of navigable waters as well as protection of water and overall environmental quality.

FIG. 1



NEW ENGLAND WATERSHEDS

2.1 THE NATURE OF FLOODING IN NEW ENGLAND

The New England region is subject to floods every month of the year. The probability is greatest in the spring when snowmelt occurs and the rivers are flowing at or near bankfull capacity for several weeks. Most of the minor and moderate floods occur during the spring runoff period and can encompass the entire region rather than a single basin. During the hurricane season, various portions of the region may be exposed to both river and tidal flooding related to the path of a hurricane. Coastal storms in any season may produce similar although usually less severe conditions.

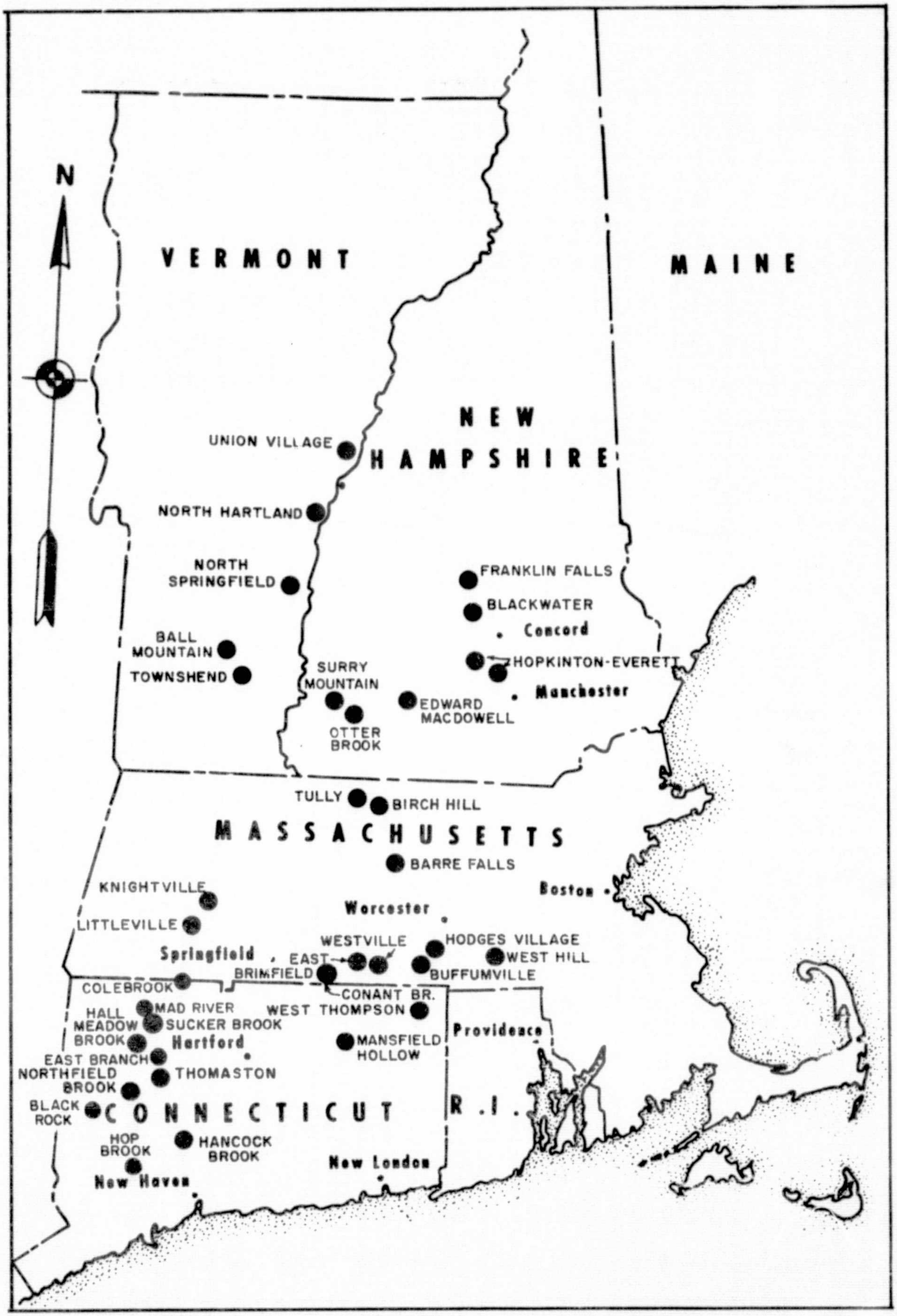
2.2 THE NEW ENGLAND DIVISION WATER CONTROL SYSTEM

Figure 2 shows locations of the Corps of Engineers flood control reservoirs in New England, most of which are in the following river basins:

Basin	Square Miles
Connecticut	11,300
Merrimack	5,000
Housatonic	1,900
Thames	1,500
Blackstone	500

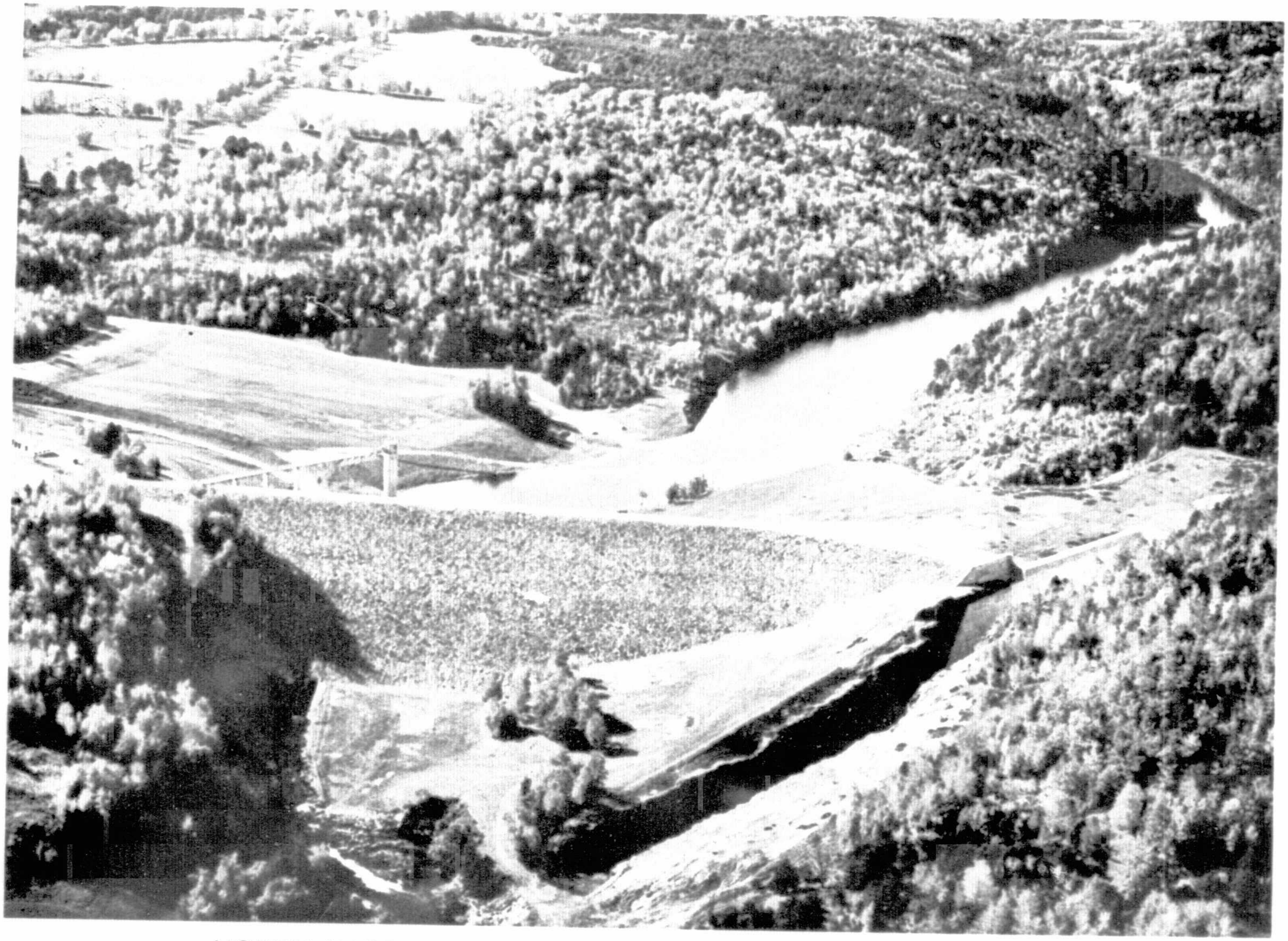
The four hurricane barriers are on the southern New England coastline -- one in Massachusetts, one in Rhode Island, and two in Connecticut.

Of the 35 reservoirs, seven hold back floodwaters automatically, with releases controlled by small ungated conduits. These projects control runoff from drainage areas of 3 to 20 square miles. The remaining 28 reservoirs, with drainage areas of approximately 25 to 1,000 square miles are gated, staffed 24 hours a day, with all storages and releases under the direction of the New England Division, Reservoir Control Center (RCC) in Waltham, Massachusetts. Figure 3 shows North Hartland Lake, in Vermont, under normal conditions, while figure 4 shows the same reservoir using 50 percent of its storage capacity to hold



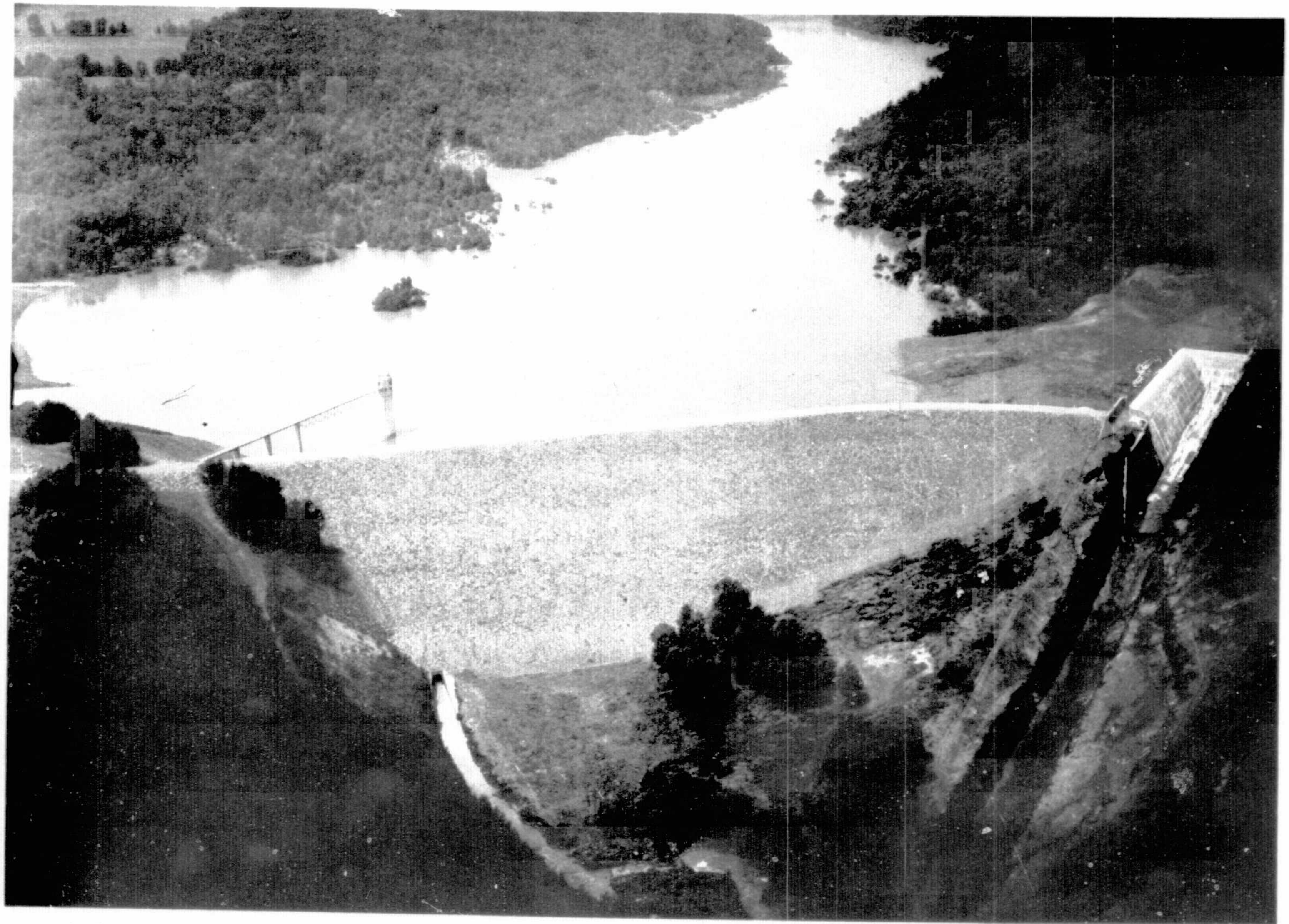
NEW ENGLAND DIVISION RESERVOIRS

FIG. 2



NORTH HARTLAND LAKE, VT. UNDER NORMAL CONDITIONS

FIG. 3



NORTH HARTLAND LAKE, VT. 50 PERCENT FULL DURING JULY , 1973 FLOOD

FIG. 4

back floodwaters of early July 1973. Figure 5, the Quinebaug River at Putnam, Connecticut in 1955, shows the type of damage that can occur in the absence of any flood control measures.

Most of the NED reservoirs are regulated initially to reduce damaging stages on their respective tributaries. Further, in each of the five river basins the reservoirs are operated as part of a flood control plan to optimize flood stage reductions at main stem damage centers. Flows are regulated to desynchronize their contributions to main stem flooding. Following a flood the stored waters are released from each reservoir as quickly as downstream conditions permit in order to have storage space available for the next flood.

Two of the four hurricane barriers have navigation gate openings, and NED is responsible for directing the closure of these gates during severe coastal storms and hurricanes to prevent damage from tidal flooding. Figure 6 is a picture of the New Bedford hurricane barrier located in New Bedford, Massachusetts.

2.3 DATA COLLECTION FOR WATER RESOURCES REGULATION

2.3.1 Introduction

Regulation of a large flood control system to prevent potential damages requires the acquisition of important hydrometeorological data on a reliable and timely basis. The types of data required and time constraints thereon have gradually increased, not only with the growing number of projects in New England, but also with the increasing complexities of functional requirements associated with the individual projects and systems. The following paragraphs will outline the manner in which the New England Division has responded to these needs to date.

2.3.2 Historical Perspective

Until the late 1950's NED did not have sufficient reservoirs in a single river basin to exert a large amount of control. Data collection was through field observation or telephone relay from instruments, with all information reaching the RCC via

THE QUINEBAUG RIVER AT PUTNAM, CONN. DURING 1955 FLOOD

FIG. 5

NEW BEDFORD HURRICANE BARRIER, MASS.

FIG. 6

telephone. Although this was time-consuming and subject to communication outages, telephone lines were considered adequate to meet regulation needs of that time.

With the growth of the flood control system over the past 15 years, NED can now effectively reduce flooding on the tributaries as well as control levels on main stems in the basins it regulates. In the 1960's a comprehensive voice radio data collection network was established in order to operate the NED flood control system. Each manned dam and hurricane barrier was equipped with a voice radio for relaying data, as well as for receiving instructions from the Reservoir Control Center. All project managers, residing at their respective dams, are responsible for obtaining and reporting data from a group of index stations, either from telephonically equipped river gages, cooperative observers or visual observations. This information usually consists of river stages and conditions at strategic locations, precipitation reports in the basin, climatologic and hydrologic data at the dams, and snow cover in the late winter and spring months.

2.3.2.1 The NED Automated Data Collection System for Real Time Management of Water Resources

Receiving reports, even by voice radio from approximately 30 projects is still time consuming; therefore, in January 1970, NED dedicated a new Automatic Hydrologic Radio Reporting Network (AHRRN). This system consists of 41 remote (unmanned) reporting stations which are situated at key index locations and report information such as river stage, reservoir level and precipitation directly to RCC in real time. Two stations provide data for the operation of hurricane barriers by reporting tide elevation, wind speed, wind direction and barometric pressure. Four ground-based relay stations transmit signals from different sections of New England to RCC. In order to bring strong, reliable radio signals from remote reporting stations to the relays, 12 repeater stations have also been established at various locations within the system. Figure 7 shows the location of the 41 remote unmanned reporting stations, 12 repeater and 4 relay stations. Table 1 lists the reporting stations and parameters.

The reporting stations and repeaters use batteries as primary sources of power. This eliminates many problems that

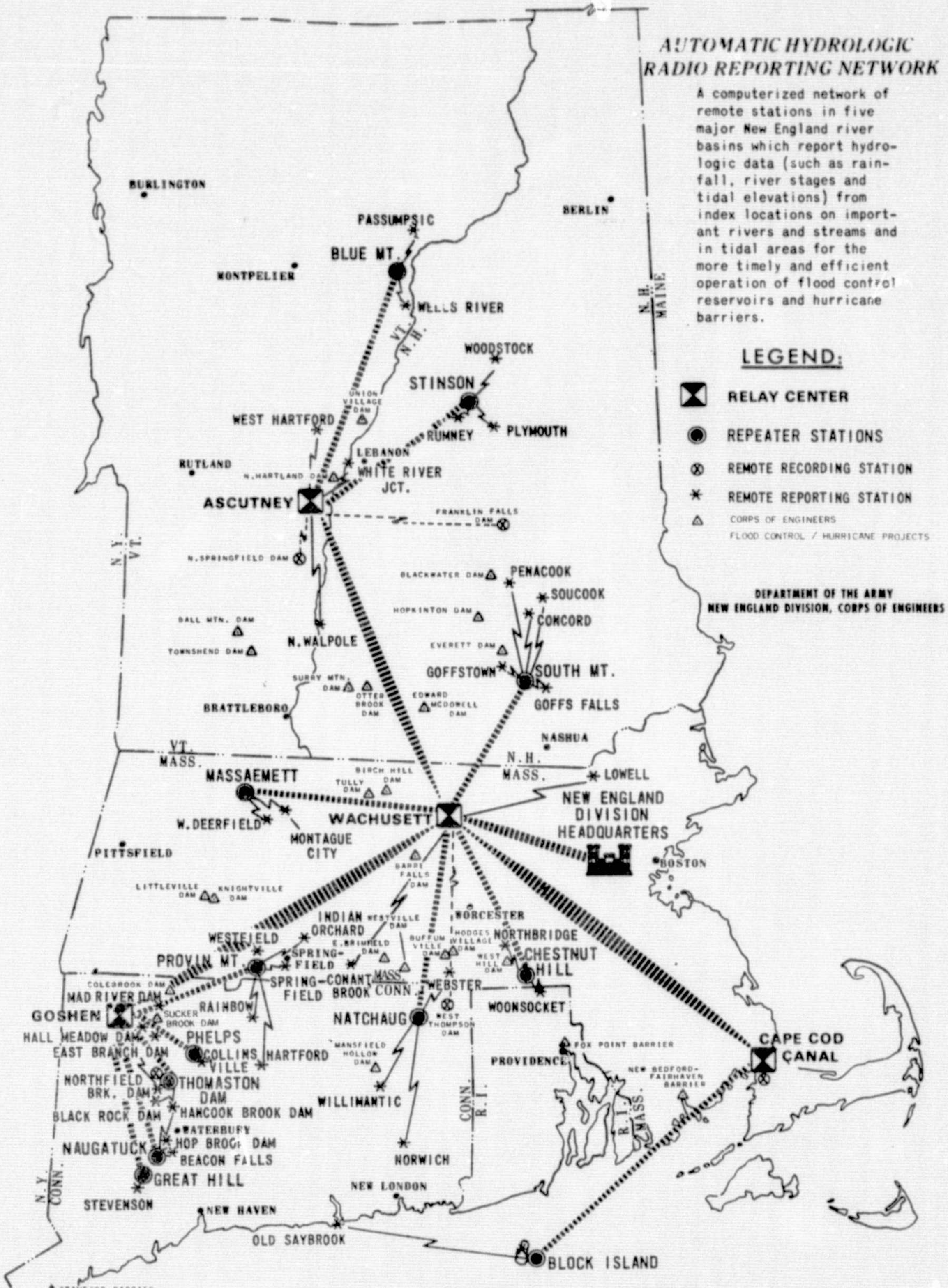

AUTOMATIC HYDROLOGIC
RADIO REPORTING NETWORK
A computerized network of remote stations in five major New England river basins which report hydrologic data (such as rainfall, river stages and tidal elevations) from index locations on important rivers and streams and in tidal areas for the more timely and efficient operation of flood control reservoirs and hurricane barriers.
LEGEND:
RELAY CENTER
REPEATER STATIONS
REMOTE RECORDING STATION
REMOTE REPORTING STATION
CORPS OF ENGINEERS
FLOOD CONTROL / HURRICANE PROJECTS
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
BURLINGTON
MONTPELIER
BERLIN
PASSUMPSIC
BLUE MT.
WELLS RIVER
VT.
N.H.
N.H.
MAINE
WOODSTOCK
STINSON
PLYMOUTH
RUMNEY
WEST HARTFORD
UNION VILLAGE DAM
LEBANON
WHITE RIVER JCT.
RUTLAND
N.HARTLAND DAM
ASCUTNEY
FRANKLIN FALLS DAM
N.SPRINGFIELD DAM
N.Y.
VT.
BLACKWATER DAM
PENACOOK
SOUCOOK
HOPKINTON DAM
CONCORD
BALL MTN. DAM
TOWNSHEND DAM
N. WALPOLE
EVERETT DAM
GOFFSTOWN
SOUTH MT.
SURRY MTN. DAM
OTTER BROOK DAM
EDWARD MACDOWELL DAM
GOFFS FALLS
BRATTLEBORO
NASHUA
VT.
MASS.
N.H.
MASS.
LOWELL
MASSAEMETT
BIRCH HILL DAM
TULLY DAM
NEW ENGLAND DIVISION HEADQUARTERS
WACHUSETT
W.DEERFIELD
MONTAGUE CITY
PITTSFIELD
BOSTON
BARRE FALLS DAM
LITTLEVILLE DAM
KNIGHTVILLE DAM
INDIAN ORCHARD
WESTVILLE DAM
WORCESTER
WESTFIELD
E.BRIMFIELD DAM
HODGES VILLAGE DAM
NORTHBRIDGE
SPRINGFIELD
BUFFUMVILLE DAM
CHESTNUT HILL
PROVIN MT.
WEST HILL DAM
COLEBROOK DAM
SPRING-FIELD
CONANT BROOK
MASS.
CONN.
WEBSTER
MAD RIVER DAM
RAINBOW
WOONSOCKET
GOSHEN
SUCKER BROOK DAM
NATCHAUG
WEST THOMPSON DAM
HALL MEADOW DAM
PHELPS
FOX POINT BARRIER
CAPE COD CANAL
EAST BRANCH DAM
COLLINSVILLE
HARTFORD
MANSFIELD HOLLOW DAM
PROVIDENCE
NEW BEDFORD-FAIRHAVEN BARRIER
NORTHFIELD BRK. DAM
THOMASTON DAM
BLACK ROCK DAM
HANCOCK BROOK DAM
WILLIMANTIC
CONN.
R.I.
R.I.
MASS.
WATERBURY
NAUGATUCK
HOP BROOK DAM
BEACON FALLS
NORWICH
GREAT HILL
N.Y.
CONN.
STEVENSON
NEW LONDON
NEW HAVEN
OLD SAYBROOK
BLOCK ISLAND
STAMFORD BARRIER

FIG. 7

TABLE 1

THE NEW ENGLAND DIVISION AUTOMATIC
HYDROLOGIC RADIO REPORTING NETWORK-REPORTING STATIONS AND PARAMETERS

STATION	LOCATION		REPORTING PARAMETERS			
	River	State	River Stage	Reser. Stage	Precip.	Tide Data*
PASSUMPSIC	Passumpsic	Vt.	X		X	
WELLS RIVER	Connecticut	Vt.	X			
WEST HARTFORD	White	Vt.	X			
WHITE R. JUNCT.	Connecticut	Vt.	X			
WOODSTOCK	Pemigewasset	N.H.	X		X	
RUMNEY	Baker	N.H.	X		X	
PLYMOUTH	Pemigewasset	N.H.	X			
PENACOOK	Contoocook	N.H.	X			
SOUCOOK	Soucook	N.H.	X			
CONCORD	Merrimack	N.H.	X			
GOFFSTOWN	Piscataquog	N.H.	X			
GOFFS FALLS	Merrimack	N.H.	X			
N. WALPOLE	Connecticut	N.H.	X			
W. DEERFIELD	Deerfield	Mass.	X			
MONTAGUE CITY	Connecticut	Mass.	X			
CONANT BRK. DAM	Conant Brook	Mass.		X		
INDIAN ORCHARD	Chicopee	Mass.	X			
WESTFIELD	Westfield	Mass.	X			
SPRINGFIELD	Connecticut	Mass.	X			
WEBSTER	French	Mass.	X			
NORTHBRIDGE	Blackstone	Mass.	X			
LOWELL	Merrimack	Mass.	X			
MAD RIVER LAKE	Mad	Conn.		X		
COLLINSVILLE	Farmington	Conn.	X			
RAINBOW	Farmington	Conn.	X			
HARTFORD	Connecticut	Conn.	X			
HALL MEADOW DAM	Hall Meadow	Conn.		X		
EAST BRANCH DAM	Naugatuck	Conn.		X	X	
THOMASTON DAM	Naugatuck	Conn.		X		
NORTHFIELD BRK. LK.	Northfield Brk.	Conn.		X		
BLACK ROCK LAKE		Conn.		X		
HANCOCK BRK. LAKE	Hancock Brk.	Conn.		X		
HOP BRK. LAKE	Hop Brook	Conn.		X		
BEACON FALLS	Naugatuck	Conn.	X			
STEVENSON	Housatonic	Conn.	X			
WILLIMANTIC	Shetucket	Conn.	X			
NORWICH**	Shetucket	Conn.	X			
NATCHAUG	Quinebaug	Conn.			X	
OLD SAYBROOK		Conn.				X
BLOCK ISLAND		R.I.				X
WOONSOCKET	Blackstone	R.I.	X			
		Total	29	9	5	2

* Includes Wind Dir., Wind Vel., Bar. Pres., Tide Elev.

** Includes both Headwater (Quinebaug R.) and Tailwater (Shetucket R.) stages.

can arise during major floods and hurricanes when power and telephone lines are down and normal means of communication fail. Batteries are charged either by thermoelectric generators or AC power where available. When the outside source of power is out, the batteries have sufficient energy to operate for about three weeks without recharging. The relays are operated on commercial power and backed up by gasoline generators.

The Automatic Hydrologic Radio Reporting Network is interfaced at the RCC to a computer and can be interrogated in either a manual or automatic mode. Under computer programmed control, reporting stations can be interrogated singly or as a group at automatically selected or various time intervals. Normally an interrogation of all stations is made every 6 hours; however, during flood periods the system is interrogated every 2 or 3 hours. During hurricanes or severe coastal storms the two coastal stations report every 15 or 30 minutes. Response time is about 3 seconds for interrogation of any given station. A complete set of readings for all 41 stations is obtained and printed out in approximately 4 minutes (see figure 8). River stage data is converted to flow and all data received at the RCC are stored in the computer for further analysis.

Also, information received at RCC is retransmitted to five strategic manned reservoirs. In addition, each of these can interrogate certain stations in its own area without going through the RCC.

2.3.3 The Need for Further Advancements in Improved Water Information Systems

Technological advancements in data collection, transmission and analysis must continue to meet the growing demand of the public in multiple use water resources management and the parallel need for preservation of environmental quality. The RCC pursues studies in those areas which show promise of implementation either to improve functions or reduce costs.

3.0 THE NEW ENGLAND DIVISION ERTS EXPERIMENT - SCOPE AND OBJECTIVES

The purpose of this study is to determine and report on the extent hydrometeorologic information received from ERTS

ALL STATION SCAN 2 FEB. 1973

COASTAL STATION	FILE NO.	DAY HR.MIN.	TIDE	BAROMETER	WIND VELOCITY	WIND DIRECTION
40 BLOCK ISLAND	54	33 2055	2.80 FT.	29.03 IN. WARN	49 MPH	225 DEGR

COASTAL STATION	FILE NO.	DAY HR.MIN.	TIDE	BAROMETER	WIND VELOCITY	WIND DIRECTION
41 OLD SAYBROOK	52	33 2055	2.50 FT.	29.12 IN. WARN	39 MPH	149 DEGR

STA. NO. AND NAME	FILE NO.	DAY HR.MIN.	DISCH.	CFS/SM	STAGE		RAIN	INCR.
98								
39 PASSUMPSIC	70	33 2055	1130.	2.6	4.00 FT.		2.65 IN.	0.17
38 WELLS RIVER	72	33 2055	7024.	2.7	4.60 FT.			
36 WEST HARTFORD	72	33 2056	840.	1.2	4.30 FT.			
35 WHITE RIVER JUNCTION	69	33 2056	11590.	2.8	8.70 FT.			
37 N WALPOLE	72	33 2056	14850.	2.7	10.90 FT.			
7 WEST DEERFIELD	73	33 2056	3234.	5.8	4.30 FT.			
6 MONTAGUE CITY	73	33 2056	21340.	2.7	14.10 FT.			
15 CONANT BROOK DAM	48	33 2056				NO REPORT		
17 INDIAN ORCHARD	72	33 2056	1500.	2.2	6.10 FT.			
18 WESTFIELD	72	33 2056	1824.	3.7	6.10 FT.			
16 SPRINGFIELD	72	33 2056	19600.	2.0	5.60 FT.			
27 MAD RIVER DAM	63	33 2057				NO REPORT		
24 COLLINSVILLE	72	33 2057	9000.	25.4	12.20 FT.	FSTG		
20 RAINBOW	72	33 2057	2210.	3.7	3.40 FT.			
19 HARTFORD	70	33 2057	20600.	2.0	7.20 FT.			
97								
34 RUMNEY	71	33 2057	387.	2.7	3.50 FT.		15.67 IN.	0.36 WARN
33 WOODSTOCK	72	33 2057	3946.	20.4	6.70 FT.		4.03 IN.	0.37 WARN
32 PLYMOUTH	72	33 2057	3450.	5.5	3.00 FT.	CHRG		
10 PENACOOK	73	33 2057	3520.	4.6	4.00 FT.			
3 SOUCOOK	69	33 2057	214.	2.8	6.80 FT.			
11 CONCORD	73	33 2058	6190.	2.6	5.30 FT.			
8 GOFFSTOWN SOUTH BR.	72	33 2058	782.	7.5	5.70 FT.			
9 GOFFS FALLS	73	33 2058	6832.	2.2	5.60 FT.			
14 LOWELL	73	33 2058	27499.	5.9	48.20 FT.			
96								
28 HALL MEADOW DAM	72	33 2058	132.	7.7	7.40 FT.			
30 EAST BRANCH DAM	71	33 2058	119.	13.0	17.30 FT.		5.80 IN.	0.00
26 THOMASTON DAM	72	33 2058	996.	10.2	26.80 FT.			
31 NORTHFIELD BRK. LAKE	72	33 2058	89.	15.7	28.60 FT.			
25 BLACK ROCK LAKE	72	33 2058	345.	15.2	39.10 FT.			
23 HANCOCK BROOK LAKE	72	33 2058	190.	15.9	8.60 FT.			
29 HOP BROOK LAKE	72	33 2059	288.	17.6	27.80 FT.			
22 BEACON FALLS	73	33 2059	6832.	26.2	9.20 FT.	FSTG		
21 STEVENSON	72	33 2059	15400.	10.0	11.60 FT.	WARN		
99 WACHUSETT RELAY	0	33 2059				NO REPORT		
13 NORTHBRIDGE	73	33 2059	−0.	0.0	−10.00 FT.	NVLD1		
12 WOONSOCKET	73	33 2059	2658.	6.4	5.30 FT.			
2 WEBSTER	73	33 2059	574.	6.7	6.60 FT.	WARN		
1 WILLIMANTIC	73	33 2059	3602.	9.0	7.10 FT.	WARN		
4 NORWICH TAILWATER	73	33 2100	12200.	9.7	24.30 FT.	WARN		
5 NORWCH HW NATCHAUG P	73	33 2100	1821.	2.4	47.01 FT.		14.06 IN.	0.55 WARN

STA. C.S.M. 2.2 HR PERIODS

39	3.65	34	5.21	33	25.56	30	−1.00	5	6.46

TYPICAL REPORT FROM THE AUTOMATIC HYDROLOGIC RADIO REPORTING NETWORK

FIG. 8

can be utilized by the Reservoir Control Center in the performance of its regulation functions related to the operation of water control projects.

3.1 DATA COLLECTION SYSTEM STUDIES

ERTS-1 has been the first earth satellite available for demonstrating the potential of satellites to relay hydrometeorological data. NED's studies with the ERTS-1 Data Collection System have had the following goals:

a. Helping evaluate the potential future usefulness of earth satellites in the relay of real time hydrometeorological data in the day-to-day operation of NED water resource projects and including: (1) the development of statistics, based on the ERTS-1 experience, that demonstrate aspects of the relationship between satellite relay and the currently existing means of acquiring this data, and (2) a preliminary investigation into the desirability and feasibility of establishing and operating a satellite network on a Corps-wide basis.

b. Assisting in evolving procedures for the selection of the most economically feasible and technically useful combination of data collection points to provide all necessary information for the optimal regulation of our water control system.

3.2 IMAGERY AND IMAGERY/DATA COLLECTION SYSTEM INTERACTION STUDIES

The analysis of ERTS imagery at the New England Division has been focused on an evaluation of the ability of the ERTS imagery to provide useful and timely supplementary hydrologic information for reservoir regulation purposes. NED's studies with the ERTS-1 Imaging System have had the following goals:

a. Determining the extent to which ERTS-1 imagery can supplement or replace present data sources in assessing various operationally useful phenomena such as:

(1) Location and coverage of surface waters, especially during flood and low flow periods.

(2) Icing conditions on rivers, lakes, reservoirs

and around hurricane barriers.

(3) Turbidity and sedimentation in lakes and reservoirs.

(4) Location and extent of snow cover.

(5) Location and extent of excessive precipitation accumulation.

(6) Tidal levels and flooding at or near hurricane barriers.

(7) Soil moisture conditions.

b. Assessing the value of the ERTS Data Collection System for providing the ground truth necessary for correlation with information acquired from the images.

The imagery portion of the New England Division ERTS investigation has been accomplished under subcontract by the University of Connecticut at Storrs, under the supervision of Dr. Paul Bock, Co-Principal Investigator.

4.0 THE NEW ENGLAND DIVISION ERTS EXPERIMENT - PROCEDURES AND RESULTS

4.1 DATA COLLECTION SYSTEM STUDIES

4.1.1 The ERTS-1 Data Collection System

The New England Division, Corps of Engineers ERTS-1 Data Collection System is comprised of 26 remote reporting stations, better known as Data Collection Platforms or DCP's. The system relays hydrometeorological information such as river stage, precipitation, wind and water quality parameters from points located all over New England to the Reservoir Control Center in near real time.

Each installation contains a sensor or sensors, a 24-volt power supply, sensor to DCP interface equipment, a weather resistant shelter, the NASA supplied DCP consisting of logic to accept up to 64 bits of data in serial/parallel or analog form and

an antenna to transmit data to the satellite. Figure 9 shows the equipment necessary for operating a precipitation station, figure 10 shows a typical river gaging site, and figure 11 shows the locations of all the DCP's. Table 2 lists the DCP's with associated pertinent information for each.

Data are transmitted by the DCP's to ERTS-1, thence to NASA's ground receiving stations at Goddard Space Flight Center in Maryland or Goldstone in California, and finally through Goddard to RCC via a teletype link supplied by NASA for this experiment. The nominal time lag, from transmission at the remote site to RCC has been 45 minutes.

4.1.1.1 The Role of the Satellite

The satellite, in a near polar orbit about 547 miles above the earth, makes a complete circuit every 103 minutes with each successive orbit displaced westward by about 1,400 miles at our latitude (between 40° and 50° N). Each day there are 14 complete orbits and the succeeding day's orbits are displaced 65 miles westward from the previous day (see figure 12). This progression allows complete imagery coverage of the entire world once every 18 days. For data collection, information is obtained whenever the spacecraft is in mutual view of an ERTS DCP and one of the ground receiving stations. Readings can always be obtained from the orbital pass nearest to our area, and often from the orbital tracks immediately to the east and west of this (103 minutes earlier and later), dependent upon the distance between the satellite and the DCP. This series of two or three data collection opportunities occurs twice daily -- during the morning when the satellite is taking pictures over the Western Hemisphere and also at night, on the 'back-side' of what are the daylight, picture-taking tracks for the Eastern Hemisphere. During each data collection opportunity the satellite is in view for a few to as many as 13 minutes between the times it appears and recedes over the horizon. The exact duration of this period depends upon how far east or west of the DCP's the pass is occurring and upon the extent to which local obstructions interfere with the fields of view of the individual DCP's. In normal operation, each DCP is continuously transmitting data at 3-minute intervals. Thus, during each data collection opportunity period NED can obtain from one to five readings from each DCP.

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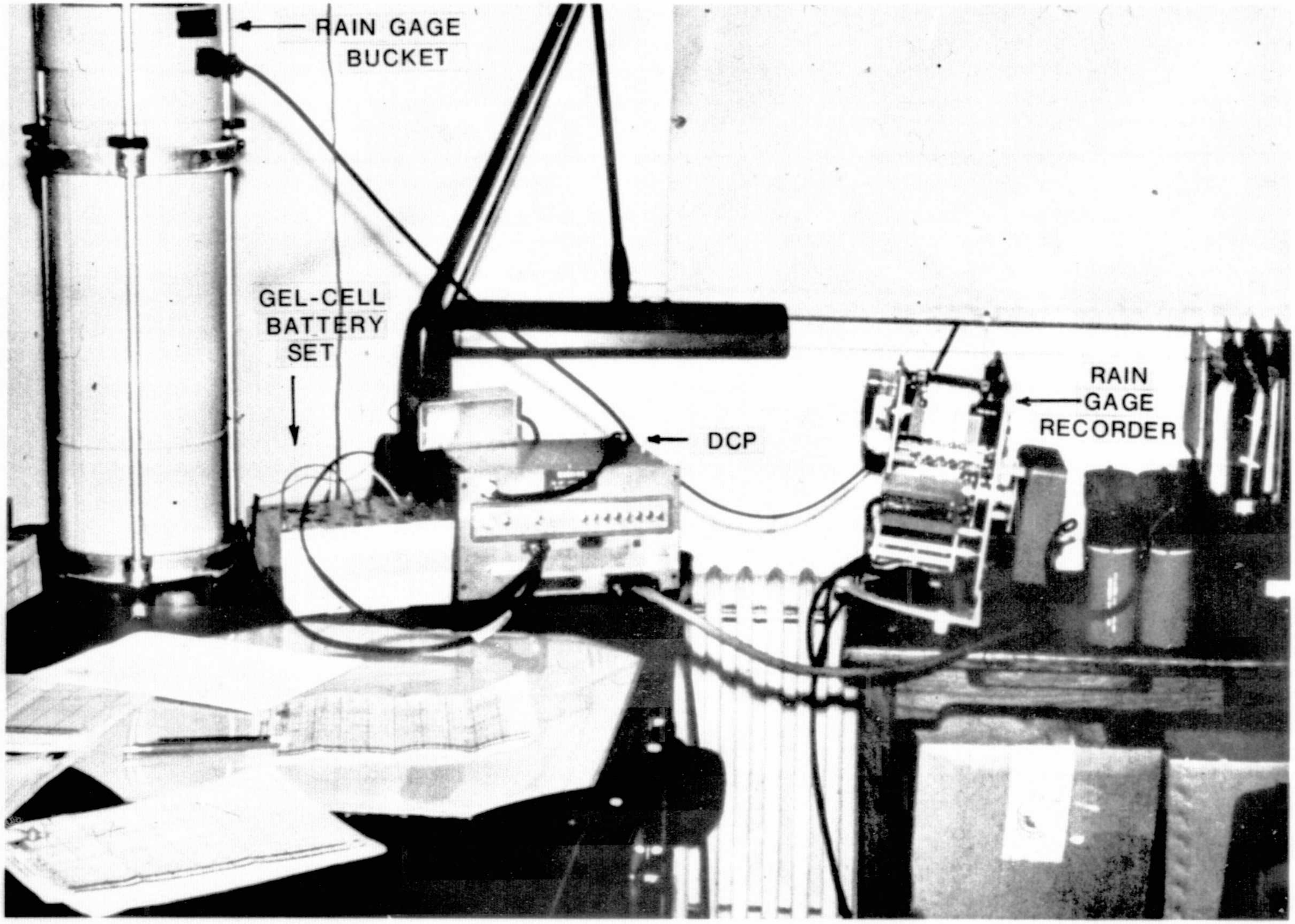


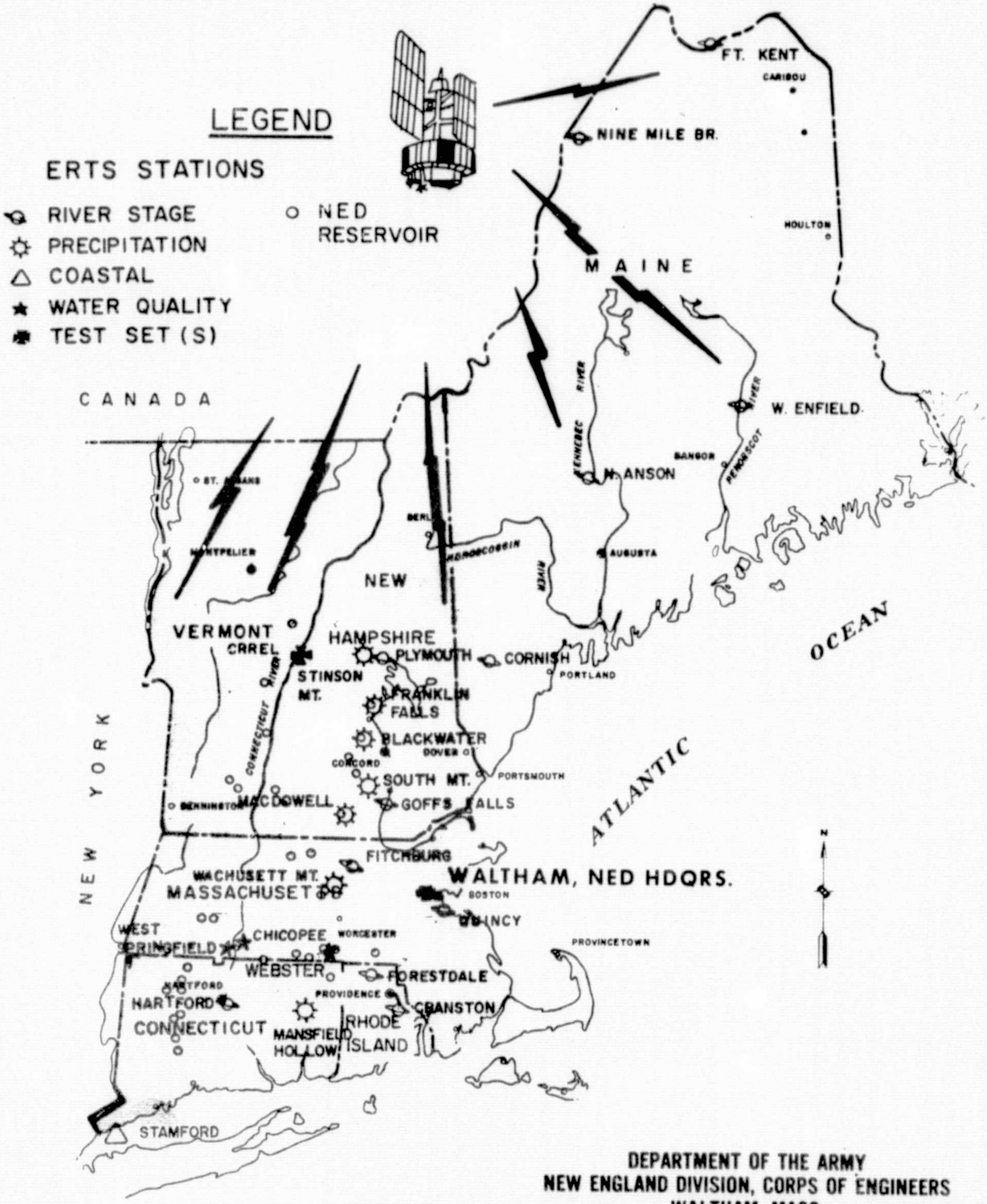
TYPICAL ERTS PRECIPITATION STATION EQUIPMENT

FIG 9

ERTS RIVER GAGING SITE
THE CARABASSETT RIVER AT NORTH ANSON, MAINE

FIG. 10

ERTS-1 DATA REPORTING STATIONS



DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1974

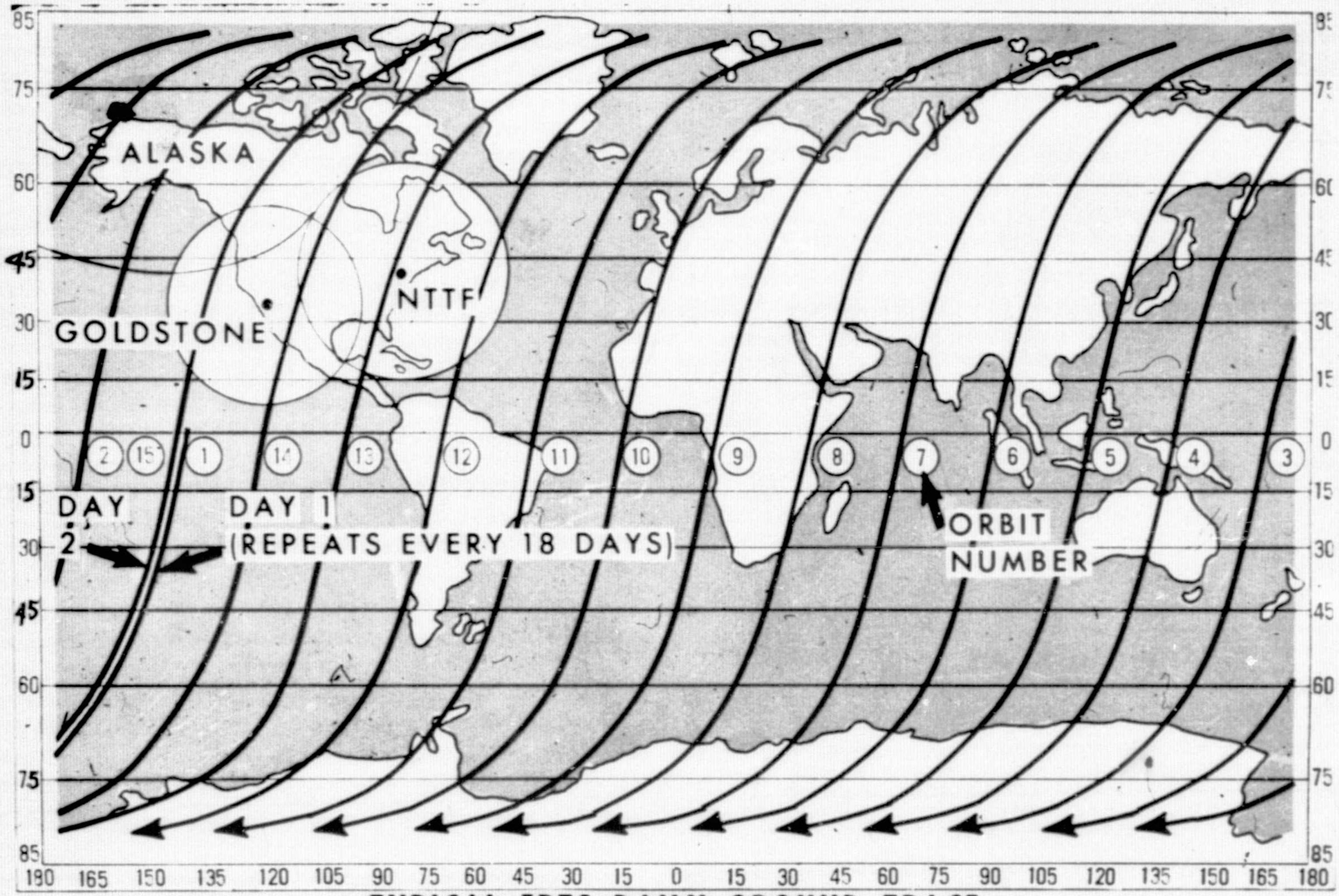
FIG. 11

TABLE 2

THE NEW ENGLAND DIVISION ERTS-1 DATA REPORTING NETWORK - REPORTING STATIONS AND PARAMETERS
9 SEPTEMBER 1974

SITE ID NO.	TYPE*	STATION NAME	LAT	LONG
1	S	SAINT JOHN RIVER AT FORT KENT, MAINE	47 15	68 35
8	S	SAINT JOHN RIVER AT NINEMILE BRIDGE, MAINE	46 42	69 43
2	S	PENOBSCOT RIVER AT WEST ENFIELD, MAINE	45 14	68 39
3	S	CARABASSETT RIVER AT NORTH ANSON, MAINE	44 52	69 57
5	S	SACO RIVER AT CORNISH, MAINE	43 48	70 47
6	S	PEMIGEWASSET RIVER AT PLYMOUTH, N. H.	43 45	71 41
7	S	MERRIMACK RIVER AT GOFFS FALLS, N. H.	42 57	71 28
10	S	TOWN BROOK AT QUINCY, MASSACHUSETTS	42 15	71 00
41	S	NORTH NASHUA RIVER AT FITCHBURG, MASS.	42 34	71 47
11	S	PAWTUXET RIVER AT CRANSTON, R. I.	41 45	71 27
13	S	BRANCH RIVER AT FORESTDALE, R. I.	42 00	71 34
12	S	CONNECTICUT RIVER AT HARTFORD, CONN.	41 46	72 40
20	P	STINSON MOUNTAIN, NEW HAMPSHIRE	43 50	71 47
21	P	SOUTH MOUNTAIN, NEW HAMPSHIRE	42 59	71 35
22	P	FRANKLIN FALLS DAM, NEW HAMPSHIRE	43 28	71 40
23	P	BLACKWATER DAM, NEW HAMPSHIRE	43 19	71 44
24	P	MAC DOWELL DAM, NEW HAMPSHIRE	42 54	71 59
26	P	WACHUSETT MOUNTAIN, MASSACHUSETTS	42 29	71 53
25	P	MANSFIELD HOLLOW DAM, CONNECTICUT	41 46	72 11
30	C	STAMFORD BARRIER, STAMFORD, CONNECTICUT	41 02	73 32
42	Q	WESTFIELD R. AT WEST SPRINGFIELD, MASS.	42 06	72 38
43	Q	CHICOPEE RIVER AT CHICOPEE, MASS.	42 09	72 35
44	Q	FRENCH RIVER AT WEBSTER, MASSACHUSETTS	42 03	71 53
50	T	NED HEADQUARTERS, WALTHAM, MASS.	42 24	71 13
51	T	COLD REGIONS LABORATORY AT HANOVER, N. H.	VARIABLE	
52	T	COLD REGIONS LABORATORY AT HANOVER, N. H.	VARIABLE	
54	T	U.S. GEOLOGICAL SURVEY, BOSTON, MASS.	VARIABLE	

* S - RIVER STAGE
P - PRECIPITATION
C - COASTAL (WIND DIRECTION, VELOCITY AND TIDE)
Q - WATER QUALITY (TEMPERATURE, CONDUCTIVITY, PH AND DISSOLVED OXYGEN)
T - TEST SET (SENSORS VARIABLE)



TYPICAL ERTS DAILY GROUND TRACE

FIG. 12

4.1.1.2 DCS Data Products

In addition to near real time relay of data from Goddard via our teletype link, computer compatible punched cards and data printouts have been provided by NASA on a regular basis via mail. The cards form the basic input to our data analysis effort.

4.1.2 DCP Installation

DCP installation for all our locations was fairly simple. Included in each DCP package were the electronic unit, antenna with 10-foot cable and all the mating connectors for the electronic unit. Beyond these items a 24-volt DC power source and connector, a connecting cable from the sensor to the DCP, a 10-foot long, 2-inch diameter galvanized pipe to mount the antenna, a 3-inch hose clamp, and clamps and bolts to attach the pipe to the gage house were required.

All components were checked by NED before installation. The DCP's were tested by a Field Test Set, power sources were tested with a voltmeter, and cables with an ohmeter. Entire units were then assembled at NED and operated through several ERTS overpasses as a final check.

Mounting the pipe on the gage house was the first and most difficult step of an installation. The procedure was to mount two clamps on an outside wall to attach the pipe; however, this often involved some imaginative and ingenious techniques depending upon the house design, construction and location.

After the pipe was installed, the antenna was set on the pipe and double clamped with its own and 3-inch hose clamps. The latter added sufficient support so that guy wires were unnecessary. Initially we used guy wires, but found that the wind could unscrew the turnbuckles. The antenna cable was then used to join the antenna and the electronic unit, passing through an orifice in the wall.

After making sure the switch on the electronic unit was in the "off" position, the cable mating the sensor and the "Digital 2" or J6 outlet of the electronic unit was connected. Finally the power source was connected to the "POWER" or J2 outlet of the electronic unit. At first we externally commoned the DCP and

sensor power supplies, but this is no longer performed since failure of the DCP programmer board often resulted.

Since we used the parallel digital mode in nearly all cases, all eight DCP word select switches were usually set to "PRL DGTL." The timer switch was then set to "90 SEC" and the DCP turned on. To see if transmissions were occurring a signal detector was placed near the antenna. If a signal was detected then the DCP timer switch was turned to "180 SEC" and installation was complete. The elapsed time of installation was essentially the time involved mounting the pipe.

4.1.3 DCP Maintenance and Performance

As of 29 May 1974, 27 data collection platforms had experienced field service, two others were used intermittently by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and an additional DCP was excluded from the statistics because it was defective since delivery.

There have been 302 operational DCP months over the entire ERTS experimental period thus far, with one DCP month equivalent to one DCP operating for one month. Over this span nine installed DCP's have experienced component malfunctions, four more than once. There has been a total of 14 DCP component malfunctions, with an average of 4.0 months' operation before malfunction. Eight occurred in two months or less, many being due to improper installation. The remaining 18 DCP's that have never experienced component malfunction are enjoying long lifetimes, some approaching two years, thus leaving normal DCP life expectancy undetermined. Table 3 summarizes DCP component malfunction statistics.

Environment-related failures of the DCP's over the entire ERTS experimental period from 23 July 1972 through 29 May 1974 have been:

Vandalism = three instances (all to the DCP antenna)

DCP site struck by a truck = one instance (damaged the antenna)

Inundation by flood = one instance

TABLE 3

DCP COMPONENT MALFUNCTION STATISTICS
(For Entire ERTS Experimental Period From
23 July 1972 Through 29 May 1974)

No	Malfunction	=	18 DCP's
One	Malfunction	=	5 DCP's
Two	Malfunctions	=	3 DCP's
Three	Malfunctions	=	1 DCP

DCP No.	Life in Months Before First Component Malfunction	Life in Months Before Second Component Malfunction	Life in Months Before Third Component Malfunction
6201	1 (p, m)	-	-
6246	2 (p, m. f)	1 (f)	2 (f)
6271	2 (p)	2 (p)	-
6220	2 (p, m)	3 (p)	-
6106	5 (f)	2 (p)	-
6170	7 (p, m)	-	-
6021	8 (p)	-	-
6071	8 (t, m)	-	-
6242	11 (p)	-	-

Component Malfunction Type:

p = programmer board
t = transmitter board
m = parallel/digital multiplex board
f = fuse

Sensor performance has been good. River stage sensors have been maintained in good working order by the U.S. Geological Survey and precipitation sensors at dams by the National Weather Service. Some problems associated with ice jams have occurred and are described in section 4.1.7.2. The remaining precipitation, coastal wind velocity and water quality instruments have been maintained by NED personnel. Heavy buildup of solid wastes has caused failure of the water quality sensors several times, leading to the removal of two water quality monitors to cleaner waters.

The 24-volt Gel-Cell battery sets (each consisting of four 6-volt batteries connected in series) have performed well. However, it appears that if a set of batteries is allowed to discharge below 20$\pm$ volts its ability to hold a recharge is greatly reduced. Such recharged batteries discharge more rapidly under load and are more susceptible to failure during cold weather than new batteries. The new sets last at least six months, with an average life of 8.2 months before failure. However, as new batteries exceed a certain age, the number of transmissions from their sites decreases, i.e., on the average, the number of transmissions from a given site remains nearly constant for the first five months of battery life, but steadily declines thereafter until complete battery failure (see figure 13).

The overall Data Collection System performance is summarized as follows:

NASA-supplied DCP equipment that survived an initial 3 to 5 month operational period after installation had a low probability of failure of approximately one in seven. Installation related failures sharply reduced as proper installation techniques became better defined and understood. Consequently 19 of the last 21 system failures (no transmissions or erroneous transmissions from a site until DCP and/or battery replaced) have been due to battery failure. Figure 14 is a chronology of the Data Collection System performance characteristics.

Faulty sites have usually been easy to detect. Most often a site simply goes off the air; however, on occasion a DCP will transmit data despite a fault. In this case, invalid bit patterns are usually transmitted. When the readings arrive at a constant ratio of bad to good in the case of river stages or when they come in streaks of totally bad, then totally good for precipitation, the

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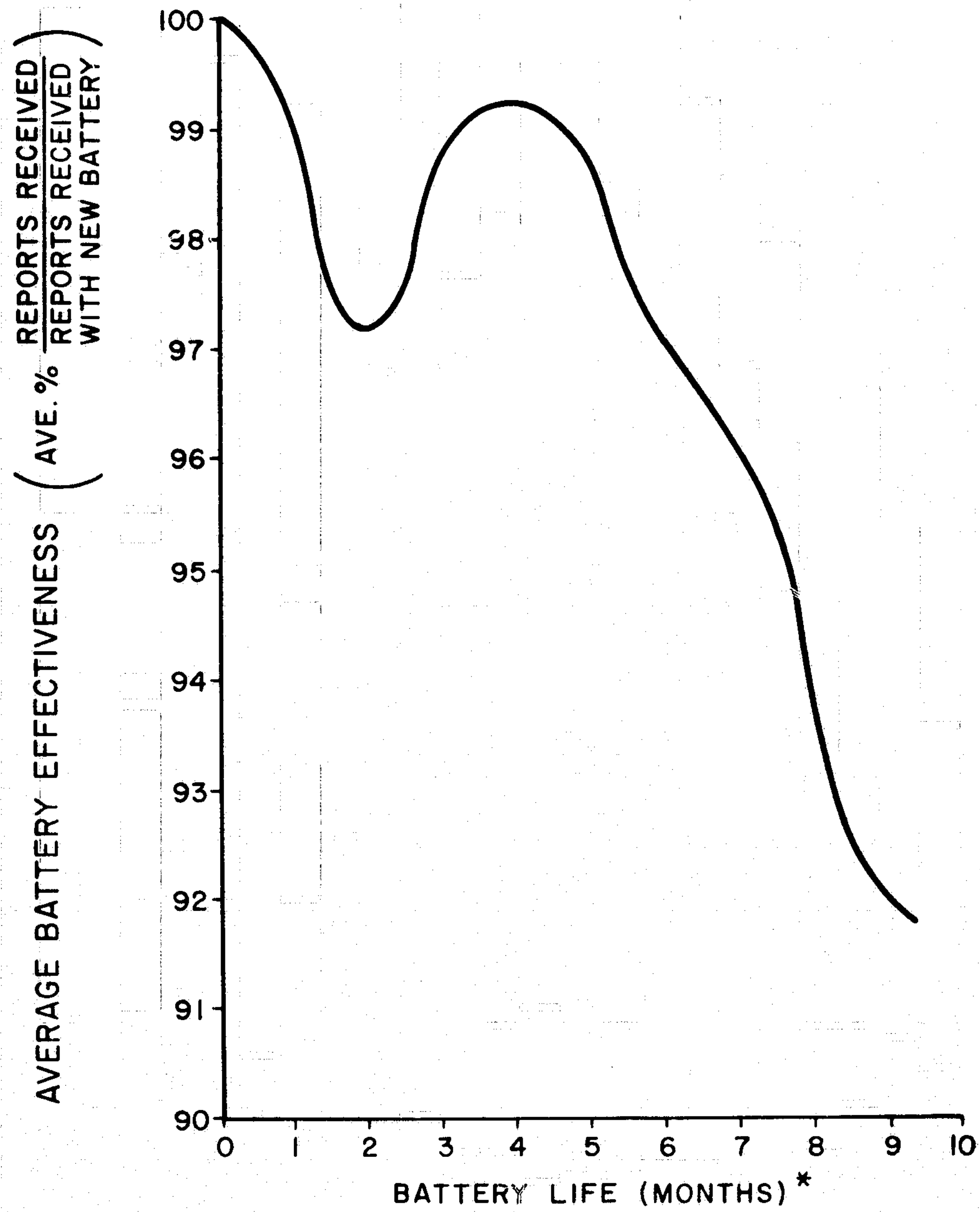

* Includes only nonrecharged batteries

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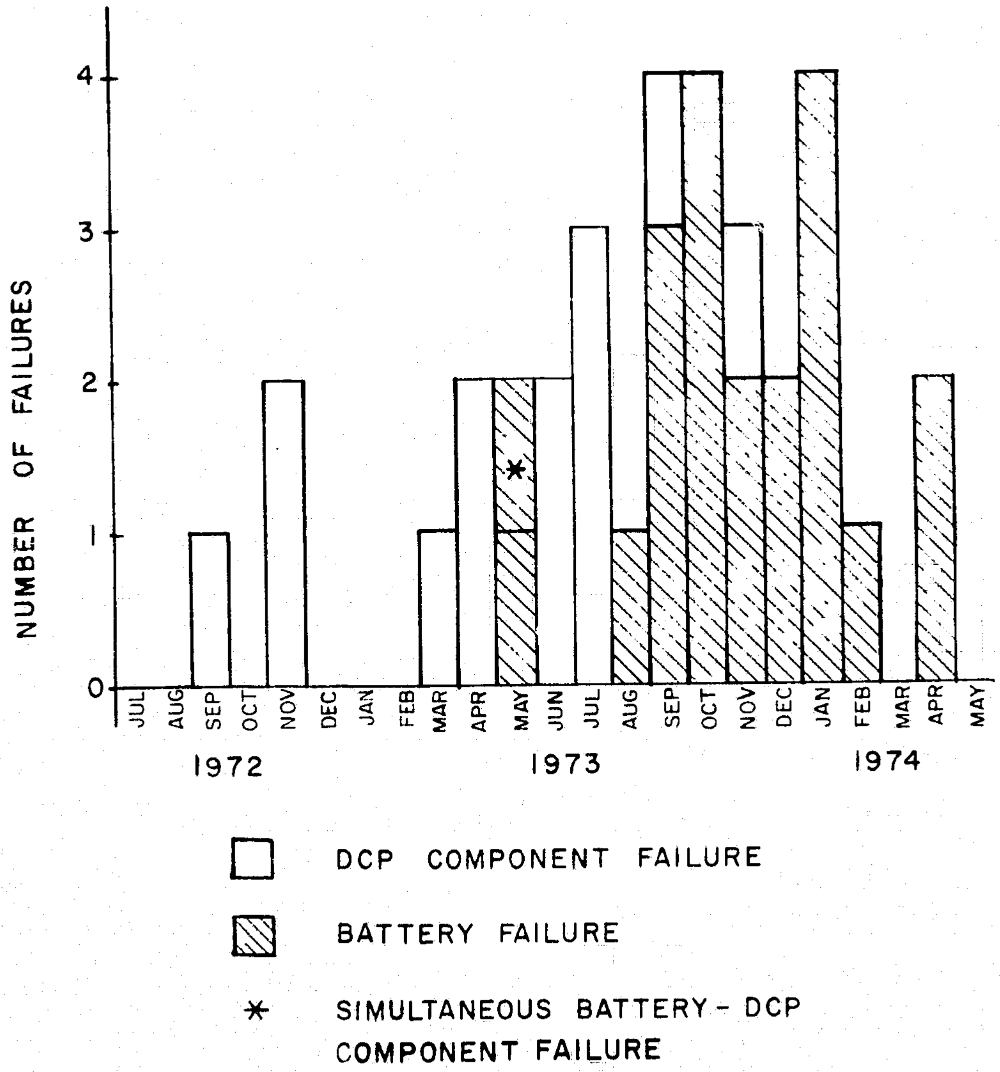
BATTERY AGE VS.

BATTERY

EFFECTIVENESS

FIG. 13



DCS PERFORMANCE

VS. TIME

FIG. 14

problem probably lies with the interface between the sensor and the DCP. However, when the good and bad readings are randomly distributed, the DCP is almost always at fault.

Because of the experimental aspect of our mission, DCP site servicing has been given a low priority, and replacement has taken two weeks in some cases. However, in an operational mode replacement need not exceed one or two days for our remotest locations. Holding a 10 percent surplus of equipment has proved adequate for all our DCP maintenance. No regular servicing of the DCP's should be necessary in an operational mode except preventive maintenance and battery replacement every six months.

4.1.4 DCS Data Analysis

The following definitions are required:

a. Signal - A radio signal sent every 3 minutes by a DCP containing station ID and sensor data

b. Message - A signal relayed by ERTS-1 to NASA

c. Report - All messages transmitted during a single pass of ERTS-1 from a particular DCP

Data were stored for computer processing from punched cards, with the data separated by DCP number and time of report, and then analyzed.

As of 20 September 1973, a significant change was made in the criteria for ERTS data transmitted from NASA to NED. Previously, only the highest confidence level (No. 7) data had been transmitted from NASA. However, meaningful operational statistics could only be derived if all data (confidence levels 0 through 7) were received at NED. So, commencing on this date, data were received from NASA regardless of confidence level. DCS reliability statistics in the following section apply only to this new data base.

4.1.4.1 DCS Reliability

In measuring the reliability of the DCS, consideration was given to comparing satellite relayed data with recorded sensor data.

However, in most instances, sensor data was recorded either every 15 minutes or every hour while DCP data was received at 3-minute intervals whenever the satellite was over the region. Visual comparisons were made of the two sets of data and it was concluded that within the time limitations they were basically the same. The DCS punched data cards contained the station identification, date and time, 64 data bits, confidence levels for the data, varying from a low of zero to a high of seven, and an error flag to denote errors in various portions of the message. DCS reliability was measured as a percentage of "Good Reports" divided by the total number of reports received. Good reports were defined as:

a. Those consisting of only one message -- a NASA confidence level of 7 and a valid bit pattern.

b. Those consisting of multiple messages at 3-minute intervals -- agreement between two consecutive messages within certain established limits and a valid bit pattern. Limits were:

River Stage -- 0.19' difference between readings
Precipitation -- 0.19" difference between readings
Water Quality -- no difference between readings

The 0.19 foot difference between river readings was selected as being the maximum that might be expected to occur during a moderate size flood and is equal to about 4 feet per hour. The same applies for the precipitation range which would be at a rate of 4 inches per hour. No difference was allowed for water quality since these values were sensed on the hour and held in storage for 1 hour. If successive values did not agree they were flagged by the computer and visually checked to see if the difference occurred at the sensing hour. For the period 20 September 1973 through 29 May 1974 results from 16 DCP sites showed 13,440 good reports versus 13,560 total reports received or a reliability percentage of 99.1. The remaining 10 sites were not included in the statistics because they did not report continuously during this period for various reasons. Technical problems with one of the three water quality monitors were not corrected until the spring of 1974. Four precipitation gages and one water quality station were not completely installed, two river gages and one coastal station reported intermittently during the period and one other site was abandoned.

4.1.4.2 DCS Data Availability

The availability of data from an operational DCP is a function of two parameters designated as follows:

a. Field of View - the openness of a site for unobstructed radio transmissions to the satellite.

b. Satellite Coincidence - ERTS-1 simultaneously within the field of view of a DCP and a ground receiving station.

DCP and battery failures and problems also influence data availability; however, replacement is so simple and can be so fast that any losses due to these need not be considered for the purposes of this discussion.

To obtain an approximation to field of view, regardless of the length of record, the following were exercised for each site location:

a. Separate the data into 18-day cycles.

b. Take the maximum number of reports received for each day with respect to the 18-day cycle (i.e., day 1 through 18) regardless of the cycle in which it occurs. For example, find the number of reports received for the sixth day of each cycle, take the maximum of these numbers and call that the number of reports possible for the sixth day of all cycles.

c. Sum the number of reports possible for each of the days as found in "b" above to find the total number of reports possible per 18-day cycle.

Based on the geographically varied locations of DCP's indications are that mountaintop sites have the best field of view (92 to 95 reports possible per 18 days); unobstructed coastal, damsite and wide-channeled river locations have good fields of view (86 to 92 reports); and obstructed locations generally have poor fields of view (78 to 84 reports). Trees represent the main obstruction in our cases, though buildings have also been a problem. A little tree trimming will generally improve field of view considerably. Field of view statistics together with descriptions of the site locations are summarized in table 4.

TABLE 4

DCP FIELD OF VIEW STATISTICS
(For Entire ERTS Experimental Period
From 23 July 1972 Through 29 May 1974)

Site ID No.*	General Location	Location Description	Reports Possible/ 18 Days
1	River	Wide river channel, DCP in open field	88
2	River	Clear view on wide river channel	90
3	River	Narrow river channel, dense woods on bank side of DCP	82
4	River	Surrounded by large overhanging trees	78
5	River	High trees on bank side of DCP	83
6	River	DCP in shadow of large tree - many other trees around	81
7	River	Clear view on wide river channel	88
8	River	Clear view on wide river channel	92
9	River	Many trees over DCP	79
10	River	Two large trees near DCP limit view	84
11	River	Two-thirds open view, one-third in shadow of trees	84
12	River	Clear view on wide river channel	90
13	River	Surrounded by many overhanging trees	82
40	River	Narrow river channel, high trees on both banks	82
41	River	Clear view	87
42	River	Trees and buildings on one side of DCP	81
43	River	Clear view	88
20	Mountaintop	Clear view	94
21	Mountaintop	Clear view	92
26	Mountaintop	Clear view	95
22	Damsite	Clear view	90
24	Damsite	Clear view	86
30	Coastal	Clear view - DCP at hurricane barrier	90

* Exact locations may be found in Table 2 except for the following which were abandoned prior to 9 September 1974:
No. 4 - Androscoggin River at Auburn, Maine
No. 9 - Charles River at Charles River Village, Mass.
No. 40 - Ashuelot River at Winchester, N. H.

Sites 23, 25 and 44 are not included in Field of View Statistics because either they were not in use during the period or not in normal operation enough to yield valid statistics

Concerning satellite coincidence, for each day and any one DCP, the total satellite coincidence consists of less than one hour. Every 12 hours ERTS-1 makes seven orbits. Of these, only two or three, 103 minutes apart, involve the relay of data from our DCP's to NASA. During the best of these, satellite coincidence lasts up to 12 or 13 minutes (maximum of five messages relayed). In the other or others satellite coincidence is considerably shorter. The total number of messages transmitted from a DCP in the course of a day is usually around 17 and rarely exceeds 20. In a situation where readings are needed every two or three hours (e.g., a flood situation) the ERTS-1 DCS is inadequate.

4.1.5 Seasonal Variation

Seasonal weather variations, including extreme winter cold (to -30° Fahrenheit) and summer heat (to 100° Fahrenheit and higher) have had no noticeable effects on the life or performance of any of the components of the DCS nor on the availability or reliability of any of the DCS data.

4.1.6 Comparison of ERTS DCS and NED's Automatic Hydrologic Radio Reporting Network

To determine the feasibility of data collection by satellite we must compare all aspects of such a system with conventional data collection techniques. Specifically at the New England Division we can compare maintenance and performance characteristics, data reliability and availability, and cost of the ERTS DCS with our current Automatic Hydrologic Radio Reporting Network (AHRRN).

For the period 20 September 1973 through 29 May 1974 the AHRRN had 37 failures in 331 operational months for an average of one failure per 8.95 operational months (an operational month is equivalent to one station operating for one month). The ERTS DCS has experienced 34 failures in 302 operational months yielding one failure per 8.88 months. While these averages are not significantly different it is noted that the 34 DCS failures included 20 battery failures which probably would not have occurred in an operational situation with routine battery replacement every six months, and several installation related failures. In other words the comparison handicaps the ERTS DCS since the AHRRN is already debugged and operational.

Like the ERTS DCS, individual station component replacements constitute most of the repairs to the AHRRN so downtime for most sites is rarely more than one or two days. However, the AHRRN relies on the use of relay and repeater radio stations, so when one or more of these fails, data from entire sections of New England are lost.

On an overall system basis, all data on the AHRRN is ultimately passed to the Reservoir Control Center by the Wachusett Relay in Massachusetts. Failure of this would be roughly equivalent to satellite failure. However, satellite failure almost always requires complete and costly replacement.

Both the AHRRN and the ERTS DCS have system reliabilities over 99 percent which easily surpasses the requirements of the RCC.

The AHRRN is activated by command from the RCC and yields real time data, while the ERTS DCS yields near real time data, but only during satellite coincidence. This represents the biggest performance difference between the ERTS DCS and the AHRRN. For RCC data must be available in real time at 2- to 3-hour intervals. With a direct downlink (ground receiving station) at the New England Division, a geostationary satellite would satisfy these requirements -- two satellites in orthogonal, nonpolar orbits might, but ERTS-1 alone is insufficient.

Two key advantages to data collection by satellite are the portability and flexibility of the data collection platforms. The DCP's can be placed in remote locations quickly, easily and without the almost prohibitive expense of setting up the additional repeater and relay radio stations necessary for comparable expansion of the AHRRN.

Preliminary cost analyses performed between an ERTS-type system satisfying RCC's requirements and the New England Division AHRRN have shown that data collection by satellite would be more economical than conventional data relay methods if employed on a Corps-wide basis with a minimum of 2,000 platforms. The AHRRN had an initial cost per station in 1969-70 of $20,000. This figure includes all equipment involved in the total system (i.e., transmitters, antennas, 4 relays, 12 repeaters and the central control facility with a computer for data readout and processing).

NED estimates the initial cost of an operational orbiting satellite data collection system to be between $5,000 and $10,000 per DCP station. This figure is based upon 2 operational satellites, 10 ground receiving stations and 2,000 DCP's nationwide. This cost per station could be decreased by adding more stations to the system.

4.1.7 DCS Operations During Flood Situations

During the New England Division ERTS-1 experiment several significant flood events occurred which proved to be of exceptional importance for the overall assessment of ERTS DCS for operational flood control purposes.

4.1.7.1 June-July 1973 Flooding in New England

A major flood occurred in Vermont and New Hampshire during the latter part of June and the first days of July 1973. Rainfall amounts for the 3-day period ending 8 a.m. on 1 July ranged up to 5 to 8 inches in the mountainous areas of the Merrimack and Connecticut River basins. This produced the largest July flood of record in the northern areas of the Merrimack, upstream of Franklin Falls Dam. The Vermont rivers which drain into the Connecticut River also experienced record levels for this time of year and caused the highest summer flood along the Connecticut River in New Hampshire and Vermont, with a lesser degree of flooding in Massachusetts and Connecticut. All flood control reservoirs in the Connecticut and Merrimack basins were closed during the flood period. Storage utilized ranged from a low of 6 percent to a high of 66 at both Franklin Falls Dam in the Merrimack and North Springfield Lake in the Connecticut, with a mean of 27 percent for the 19 reservoirs involved. Estimates are that the flood control system in the Connecticut River basin prevented $27 million in damages and the Merrimack system $3 million, for a total of $30 million.

The ERTS-1 Data Collection System demonstrated the potential usefulness of real time data relay by satellite during the entire 6-day flood period. ERTS DCS showed that reliable data can be obtained with no adverse effect upon the system's performance from the stressful meteorologic and hydrologic conditions. However, the frequency of data relay from the present satellite configuration was inadequate for operational flood control purposes.

A reporting interval of 2 or 3 hours is essential for flood regulation in New England.

Nevertheless, data relayed by ERTS-1 proved useful in augmenting the information obtained through existing New England Division data collection methods. DCP's provided data from remote river gages in the State of Maine, from which real time data is not otherwise obtainable. The Androscoggin and Saco Rivers reached flood stages and ERTS monitoring followed the progress of these events.

This contribution proved useful in obtaining a more complete picture of the flood to help Corps emergency coordination activities in watersheds where there are no flood control projects. The information was also forwarded to the U.S. Geological Survey and the National Weather Service River Forecast Center for their use during the critical stages of this flood period.

ERTS-1 also provided data from several rivers in highly urbanized areas of southeastern New England to contribute to the overall flood picture.

4.1.7.2 Annual Spring Floods in Northern Maine

Rivers in northern Maine are subject to annual spring flooding as a result of melting snow. These floods are occasionally of considerable magnitude, especially when aggravated by unseasonably warm temperatures or heavy rains. Because of man-made developments along its banks, the Saint John River in northernmost Maine is particularly associated with damaging floods. Fort Kent is the first major town in the path of the floodwaters.

The DCP located at Fort Kent successfully monitored record flood conditions in May of 1973, once again proving the utility of satellites for real time relay of data from geographically remote areas. As a result of this experience and a meeting between officials from Canada and the United States, the DCP at Ninemile Bridge, in the headwaters of the Saint John, was established in July 1973. This key index station for flood forecasts of the river is inaccessible during the spring runoff period and has never been attainable for near real time data acquisition.

Beginning 1 April 1974, the New England Division began relaying information from the DCP's on the Saint John River in Maine on a daily basis to the New Brunswick Electric Power Commission to evaluate a new flood forecasting computer program. On 1 May, the flood of record occurred at Fort Kent, exceeding the previous year's stage by about 2 feet. Unfortunately, ice jams at both DCP locations caused serious problems for the river gages during this runoff period. At Ninemile Bridge, ice jamming near the gage first caused unnaturally high stages, rendering the data useless for forecasting purposes; later the ice damaged the gage itself causing the transmission of meaningless information. At Fort Kent, useful information was obtained up to the time of the flood peak, when a breaking ice jam destroyed the gage, and damaged all equipment beyond repair.

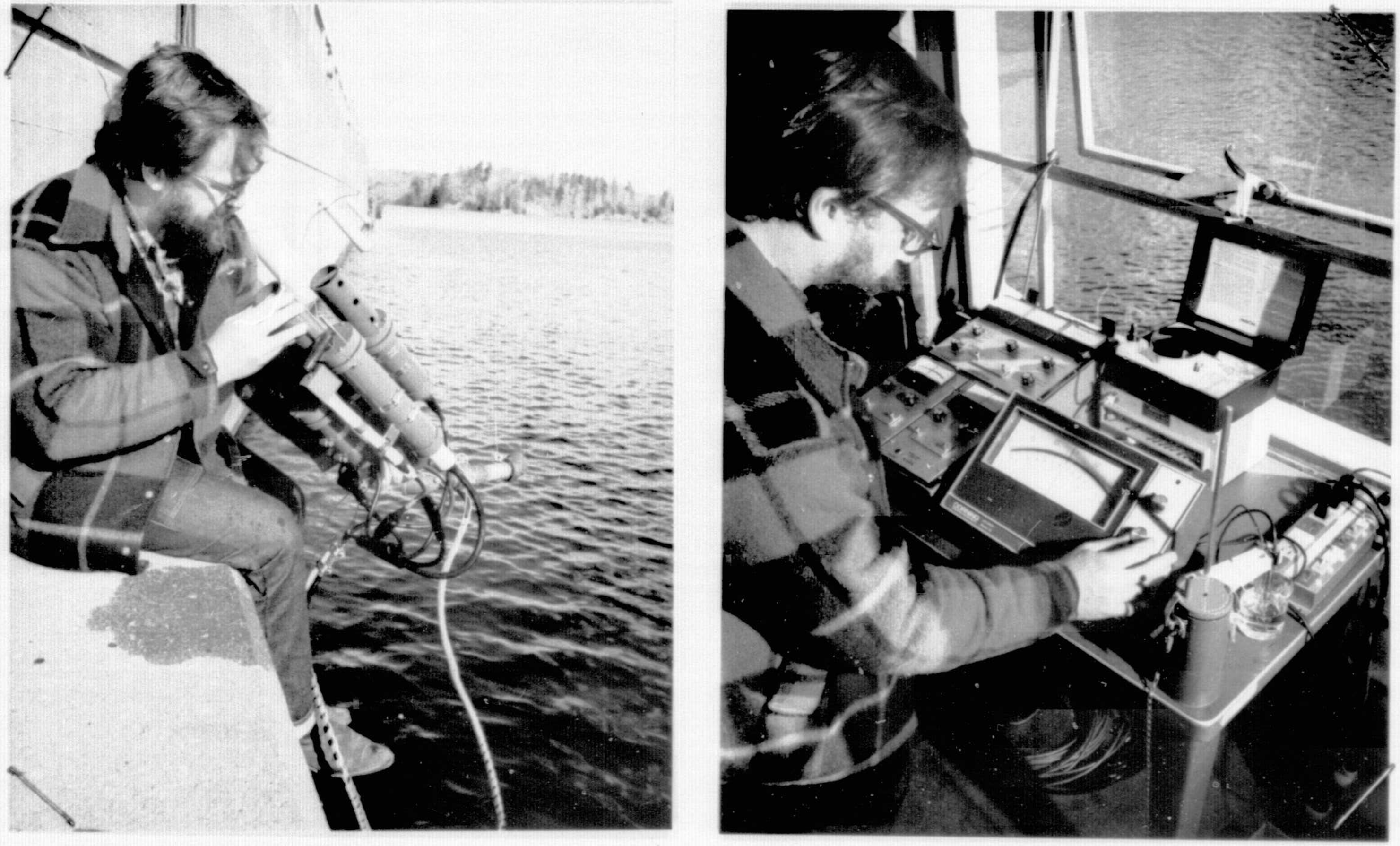
The 1974 experience re-emphasizes the utility of satellite relay of data from these remote areas, but at the same time makes all the more urgent some action concerning the effect of ice jams on river gaging activities.

4.1.8 Sensor Development and Testing by the Cold Regions Research Laboratory

During the ERTS-1 experimental period CRREL used two DCP's to intermittently interface temperature and other environmental sensors. A thermal diode developed at CRREL was successfully tested in both air and soil; a commercially purchased anemometer was also interfaced with no difficulty.

4.1.8.1 Water Quality Monitoring at Wilder Dam

A Martek water quality monitoring system containing sensors measuring probe depth, water temperature, conductivity, pH and dissolved oxygen (see figure 15) as well as a sensor measuring air temperature was installed for test purposes at Wilder Dam on the Connecticut River in New Hampshire by CRREL on 29 October 1973. The system, interfaced with a DCP, was in operation until 19 December 1973. The site proved to be an ideal location, considering the variable parameters, convenience of a shelter for equipment housing and availability of external power. At times heavy debris concentrations passed the sensors. Logs as long as 14 feet were snagged without damaging the sensors or significantly influencing the sensor readings (a slight change in



WATER QUALITY MONITORING SYSTEM USED BY CRREL AT WILDER AND LIBBY DAMS

FIG. 15

depth was noticed). Calibrations were performed on 29 October and 5, 13 and 19 November. The sensor package maintained an acceptable degree of accuracy during the test period. Data received through the ERTS data collection system was comparable with ground truth information recorded by the instruments.

4.1.8.2 Water Quality Monitoring at Libby Dam

To further demonstrate its operational capabilities to Corps of Engineers planners and operations personnel, the water quality sensors and the DCP were taken to Libby Dam on the Kootenai River in Montana. Using commercial power the unit was installed below Libby Dam for one day on 15 February 1974 by CRREL, in cooperation with the Environmental Resources and Water Quality Sections of the Seattle District, Corps of Engineers. It was then moved to a buoy in the impoundment area behind the dam and operated for 2-1/2 days. During this time the sensors were powered by a 12-volt lead acid battery plus a 6-volt dry cell battery for the stirrer in the dissolved oxygen analyzer. The limit of unattended service for both batteries was estimated to be about one week before replacement would be required. The DCP was powered by a 24-volt Gel-cell battery set. Finally, the unit was placed below the dam again where it operated continuously on commercial power from 18 February to 28 May 1974. The air temperature sensor and a rain gage were added from 6 April through the end of the experimental period.

The DCP transmissions were relayed by ERTS-1 to NASA Goldstone and Goddard and then through Goddard by teletype to the New England Division; NED then telephoned the data to CRREL; at CRREL the information was entered on computer tape and teletyped back to Libby Dam and to the Seattle District, Corps of Engineers office. Transmissions from the DCP to the users at the dam and in Seattle were able to be accomplished in a total elapsed time of 4 hours. Despite the roundabout relay pattern this is about the same time as presently required at the dam to take the measurements manually.

4.1.9 DCS Optimal Layout Study

The purpose of this aspect of the New England Division experiment was to help evolve procedures for selecting the most economically feasible and technically useful combination of data

collection points to provide all the necessary information for the optimal regulation of our flood control system. The prototype study was to have taken place using the DCP's concentrated in the Merrimack River basin. This entire study is being deferred to our ERTS-B follow-on investigation so as to permit it to take place simultaneously with the testing and evaluation of a complex flood forecasting and routing computer program for the Merrimack developed at the Corps Hydrologic Engineering Center, Davis, California and delivered to NED in April 1974.

4.1.10 ERTS-1 Data Collection Workshop

On 30-31 May 1973, a workshop was held at NASA's Wallops Station, Virginia with the purpose of providing a forum for the discussion of the various user experiences with the ERTS-1 Data Collection System. This meeting was the first major gathering ever of those groups working with, and interested in, satellite relay of earth resources data. The meeting further, and more importantly, was expected to lead to discussions of the future of data relay by satellite and automated data collection, in general, in light of the data collection needs of the various groups in attendance.

Approximately 90 people from various Federal agencies and several universities attended the workshop. Messrs. Cooper, Horowitz and Finegan represented the New England Division. Mr. Cooper was Chairman; Mr. Horowitz, Recording Secretary and Mr. Finegan presented a talk, entitled: "Use of ERTS-1 DCS in the Management and Control of Water Resources Systems."

Presentations made by ERTS-1 DCS users attending the workshop indicated that space technology has expedited the gathering of data for better understanding and management of earth resources. Hydrology and water resources have been the disciplines of greatest concentration of user interest. ERTS DCS was reported to be amenable to a wide variety of physical locations with data collection platforms being easily installed. Severe climatic conditions caused little detrimental effect on the operating platforms. Ability to obtain data from remote areas previously unobtainable on a real time basis was mentioned as a significant breakthrough for data collection by satellite. There was complete agreement as to the overall success of the satellite data collection concept. Several technical papers were presented to update users on developments

in ERTS-1 data collection platform related equipment. Representatives from NASA and the National Oceanic and Atmospheric Administration gave up-to-date information on plans for further satellite systems.

On the second day of the workshop, presentations were made by upper echelon representatives of the U.S. Department of Interior, National Oceanic and Atmospheric Administration, Environmental Protection Agency and the Corps of Engineers regarding data collection requirements and present and proposed programs of the respective agencies. The group was also addressed by Mr. Charles Mathews, Associate Administrator, Office of Applications at NASA.

There was general agreement by the workshop participants that an operational satellite data relay system is desirable and should be compatible to the needs of all potential user agencies. Recommendations were made at the meeting that:

a. NASA maintain the ERTS-1 or a similar DCS capability until such time as an operational system is in existence.

b. An Ad Hoc Interagency Committee be formed to coordinate study and development of satellite data collection systems leading to early deployment of an operational system to meet agency missions, and consideration of the international aspects of satellite data collection.

The meeting was very informative as well as invaluable in bringing together all major data collection interests for consideration of the future of automated data collection. Continuing contact with the participants has shown that the Wallops Workshop may have ignited the spark necessary to properly direct the future of this important aspect of remote sensing. To further this goal, the Preliminary Proceedings were published and distributed to all attendees in early 1974, with final publication as NASA SP-364 in 1975.

4.1.11 Questionnaire to Determine Corps-Wide Need for Automated Data Collection

A questionnaire was sent to all Corps of Engineers offices in July of 1973 to obtain information on current Corps-wide

data collection facilities and projected future needs. A copy of the questionnaire with the tabulated results follows.

. The need, over the next five years, for nearly 4,000 fully automated data collection stations is far more than required for an economical Corps-wide operational orbiting satellite system as compared with ground-based methods (see section 4.1.6). In view of the potential orbiting satellite configurations, where continuous or hourly data is difficult to access, we intend to requestion all Corps offices which requested data on these bases. We expect that in most instances receipt of the data in a longer time frame would be acceptable. Two satellites in orthogonal orbit could provide data once every two hours. A geostationary satellite would satisfy all requirements; however, the economic feasibility of this has yet to be determined.

4.1.12 Conclusions and Recommendations

NED concludes that data collection by orbiting satellite relay is both reliable and feasible. Orbiting satellite systems can be designed that are more flexible, easily maintained and less expensive than conventional ground-based means.

The only drawback with the ERTS-1 DCS for NED operational purposes is the frequency of data reports (four to six times daily). However, it should be emphasized that the ERTS-1 DCS is an experiment to test the feasibility of data collection by orbiting satellite. An operational system could be designed involving more than one satellite, to increase the frequency of data reporting.

Based on its ERTS-1 experience, NED endorses the institution of a satellite data collection system on a Corps-wide basis or a nationwide system with other Federal and State agencies, whether it be of the orbiting type with which we have experimented, or the geostationary kind, for which evaluation is not yet available.

Since any operational satellite configuration should include ground receive stations at all major user locales to enable direct receipt of information from the satellite or satellites rather than acquisition from a national center, NED, with NASA support, is constructing an inexpensive semiautomatic and easily maintained ground receive station. This is expected to further demonstrate the utility of satellite data relay by testing a system in a quasi-operational mode.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO R AD
WALTHAM, MASSACHUSETTS 02154

REPLY TO
ATTENTION OF:

NEDED-W

17 July 1973

SUBJECT: Request for Information for Real Time Data Collection System

Division Engineers
District Engineers

1. As a principal investigator for NASA's ERTS-1 program, the New England Division is actively engaged in an experiment to determine the feasibility of collecting hydrologic information via satellite. With financial support from NASA, NED has established a network of 27 remotely located data collection stations that report river stage, rainfall, coastal wind and tide information and water quality parameters throughout the New England area.

2. One aspect of the NED experiment is to determine the economic and hydrologic viability of satellite data relay in relation to past, present and future configurations in terms of cost, reliability and timeliness. Based on the status to date, NED confidently reports that data relay by satellite is completely feasible and reliable. The system has operated through the winter and spring runoff period and information actually is being utilized in an operational mode, especially in areas where no other data are available.

3. The recommendations resulting from this experiment could have Corps-wide implications. In order to be cost effective a satellite oriented system would have to provide nationwide coverage and regional readout centers. In fact, it might even require a coordinated system of all Federal and other agencies involved in data collection.

4. On 30-31 May 1973, we organized a workshop at Wallops Island, Virginia to further explore the status of the present experimental satellite data collection system and future data collection needs and

requirements of all government agencies. At this meeting there was general agreement that an operational satellite data relay system is desirable and should be compatible for the needs of all potential user agencies.

5. In order for our experiment to be meaningful, we request that you complete and return the inclosed questionnaire by 15 September 1973. Please include all stations from which data would be useful in water management activities except those continuously manned on a 24-hour basis. Also indicate if you would like a copy of the results of this questionnaire. If you have any questions please contact Mr. Saul Cooper at 617-894-2400, extension 627.

FOR THE DIVISION ENGINEER:

Saul Cooper

1 Incl
as

SAUL COOPER
Principal Investigator

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02154

REPLY TO
ATTENTION OF:

NEDED-W

17 December 1973

SUBJECT: Results of Questionnaire on Real Time Data Collection Systems

Division Engineers
District Engineers

1. All Districts and Divisions responded to the questionnaire and the data have been compiled, summarized and tabulated. A copy of the results is inclosed for your information.

2. During telephone conversations with the Districts and Divisions it was pointed out that by "real time data", we meant unmanned, automated stations. This has been reflected in the summary which shows that 3,970 of 4,437 proposed stations would be fully automated.

FOR THE DIVISION ENGINEER:

1 Incl
as

Saul Cooper
SAUL COOPER
Principal Investigator

QUESTIONNAIRE
TO DETERMINE THE CORPS-WIDE NEED
FOR AUTOMATED DATA COLLECTION

RESPONSE: ALL DIVISIONS-ALL DISTRICTS

A. At present does your office collect hydrologic or other environmental data from field locations on a near real time basis?

YES ☐ NO ☐

B. If the answer to (A) is "Yes", enter the number of locations:

Telemark	☐	623
Ground-based radio relay	☐	844
Earth satellite relay	☐	—
Other (specify type) (Telephone and/or Teletype)	☐	2347
METS SYSTEM		46
TOTAL		3860

(Use additional pages for continuation)

C. Enter the number of locations reporting each of the parameters listed below:

River stage	☐	1971
Precipitation	☐	2230
Snow cover	☐	925
Wind speed and/or direction	☐	109
Barometric pressure	☐	37

Tidal levels & Oceanographic	☐	108
Air or soil temperature	☐	168
Air or soil moisture	☐	48
Water quality	☐	345
Other (specify type)	☐	181
TOTAL:		6122

(Use additional pages for continuation)

D. How many field locations do you feel would adequately fulfill your near real time data collection needs as projected over the next five years? ☐ 4437

E. Maximum number of parameters at any one site ☐ 2-27

Minimum number of parameters at any one site ☐ 1-5

Average number of parameters at any one site ☐ 1-15

F. Based on your 5-year project in question D, enter the required number of locations to measure each of the following parameters:

Column 1 - Parameter

Column 2 - Number of locations

Column 3 - Frequency desired such as "continuous", "every so many hours", "days", "weeks", etc.

Column 4 - How important to interrogate on call - (1) indicates very important and (5) indicates no need.

(1) Parameter	(2)	(3)	(4)
River stage			
Precipitation			
Snow cover			
Wind speed and/or direction			
Barometric pressure			
Tidal levels			
Air or soil temperature			
Air or soil moisture			
Water quality			
Other (specify type)			

G. How many stations would you expect to place in each of the following types of physical locations?

Along rivers or lakes	☐	2171
At coastal sites	☐	157
On mountaintops	☐	116
In woods	☐	120
In fields	☐	206
In the middle of a town or city	☐	214
Other (specify) **Unspecified**	☐	1453
TOTAL:		4437

(Use additional pages for continuation)

SUMMARY OF ERTS QUESTIONNAIRE

INTERROGATION TIME REQUIREMENTS

PARAMETERS	Number and Time of Parameters										
	Continuous	1-Hour	2-Hour	3-Hour	6-Hour	8-Hour	12-Hour	24-Hour	Weekly	2-Week	Totals
River Data (Stage, Tailwater, Current, Discharge)	732	480	60		227	325	23	106			1953
Precipitation	310	430	36	351	240	17	100	361			1845
Reservoir or Lake Stage	21	17	19		17						74
Snow Cover	84	10	7		319			75	68		563
Wind Speed and/or Direction	42	10				8		193			253
Barometric Pressure	10							16			26
Oceanographic Data (Tide Level, Current, etc.)	87							94			181
Air or Soil Temperature	10	55	3					190		20	278
Air or Soil Moisture		60						49			109
Water Quality Data	154	49		3	8		1	187	26	20	448
Evaporation								10			10
Spillway Gate Opening		15									15
Solar Radiation		5									5
Totals	1450	1131	125	354	811	350	124	1281	94	40	5760

4.2 IMAGERY AND IMAGERY/DATA COLLECTION SYSTEM INTERACTION STUDIES

The purpose of the ERTS-1 imagery investigation is to develop practical uses of the imagery in support of reservoir management and control operations within the New England Division.

The analysis of the ERTS imagery is directed toward development of operational benefits derived from improved NED operations rather than to "research" objectives per se. The thrust of the study is to integrate interpretations of the imagery analysis with DCS information, data from the Automatic Hydrologic Radio Reporting Network (AHRRN) and that from other conventional sources. The study is intended to explore the potential of ERTS imagery in contributing toward an improved information base for timely reservoir management decisions of the NED Reservoir Control Center.

ERTS photo products have been used in essentially the same form as they are produced at the NASA Data Processing Facility (NDPF). Simple scale magnification and standard photo interpretation techniques have been employed for plotting transferred imagery information onto overlays.

A color-additive enhancement technique using the inexpensive Diazo process was used to produce color composites of various combinations of MSS bands for various dates. These indicate additional useful information can be interpreted from the color composites.

Computer-oriented imagery processing has been investigated. Available ERTS computer compatible tapes (CCT's) were used to produce image printouts in selected spectral bands with alpha-numeric symbols representing resolution elements of given density levels.

A man-computer interactive system using Cathode Ray Tube (CRT) and light pen for interpretation of ERTS imagery has been studied. Computational algorithms have been devised to efficiently program and display useful information related to the ERTS imagery. A limited experiment using ERTS MSS frames imaging the Cape Cod Canal has demonstrated useful, preliminary

results. The following section gives definitions of "remote sensing" and "resolution" which are used throughout the imagery and imagery/DCS portions of this report.

4.2.1 Definitions of Remote Sensing and Imagery Resolution

The term "remote sensing" is variously defined in the literature. Most generally, remote sensing is "the art of sensing objects remotely." The human eye sensing a scene is the classic example.

A definition which stresses the role of the entire electromagnetic spectrum is "sensing at a distance using ultraviolet, infrared and radio frequency wavelengths to supplement the visible-region sensors." Here, for example, sensors such as radars operating in the "invisible bands" are explicitly included.

A more general definition which shows that remote sensing need not be restricted to the use of electromagnetic wavelengths follows: "Remote sensing is the acquisition of information about specific objects in which the information gathering device is not in intimate contact with the specific objects under investigation. Such information includes measurements of force fields, by gravity meters and magnetometers; of electromagnetic radiation, by cameras, infrared detectors, radar systems, and radio frequency receivers; of accoustical energy by seismographs and sonars; and of phenomena associated with radioactivity."

Perhaps the broadest definition related to earth observations is that of Holter[1], "Remote sensing denotes the joint effects of employing modern sensors, data processing equipment, information theory and processing methodology, communications theory and devices, space and airborne vehicles, and large systems theory and practice for the purposes of carrying out aerial or space surveys of the earth's surface." The concept of a multidisciplinary, systems-oriented approach is reflected in this definition.

For the purposes of this study, the term "remote sensing" implies the use of the ERTS-1 sensors; namely, the Return Beam Vidicon Camera (RBV) and Multispectral Scanner (MSS) to acquire information about earth features and phenomena of interest to NED. The use of the ERTS DCS capabilities in association with the image sensors is included in the term "remote sensing".

Based on the previous definitions, the elements of remote sensing include:

<u>Sensor</u> - A device which senses the signal from the remote object (for example, a camera or multispectral scanner).

<u>Platform</u> - A carrier that transports or houses the sensor (for example, aircraft or spacecraft). Not to be confused with an ERTS Data Collection Platform, or DCP.

<u>Platform Peripherals</u> - Devices used for data relay and communication, navigation, location, positioning, power, etc.

<u>Operator</u> - Either a manual or automated control device which causes the sensor and other system components to perform according to plan (for example, a man or computer program).

<u>Data Processor</u> - Converts output of sensor into analog or digital format for interpretation (for example, a detector, multiplexer, photo lab, a computer program to draw a "map").

<u>Interpreter</u> - Usually, the final user of the output of the data processor (for example, the NED user may subjectively "eyeball" an ERTS image or rely on computerized pattern-recognition techniques).

<u>Interpreted Product</u> - The analyzed output of the interpreter, the useful product of the remote sensing system (for example, an analyzed ERTS MSS frame, a report, a snow map, an estimation of turbidity in lake waters).

In the performance of the research tasks involving the imagery and imagery/DCS portions of this investigation, we were concerned primarily with the last three elements, namely, the data processor, the interpreter, and the interpreted product.

To gain a fuller understanding of the applications of remote sensing, the term "resolution" must also be defined. This is simply what one is able to "see", "detect", or "recognize" on a photograph or image. According to Rosenberg, Erickson and Rowe[2], "Resolution in a photograph is the minimum separation between test objects, or between the elements of a test pattern, such that the images of the objects or of the pattern elements are discerned as

separate or distinct from each other. Resolution in a photograph is a complicated function of: shape of the test object or of the pattern elements, e.g., bars or circles; ratio of length to width if the test pattern is made of bars; contrast ratio; edge sharpness of test pattern; visual acuity of the observer; illumination used by the observer, etc."

In the practical terms used in this investigation, resolution in general, refers to our ability and accuracy to determine two characteristics from ERTS imagery and/or from computerized maps derived from the computer-compatible tapes of the imagery; namely, (a) spectral characteristics of hydrologic features (for example, the differences in reflectance values between land and water when attempting to differentiate between land and water surfaces, and (b) spatial characteristics of hydrologic features (for example, lengths and widths of streams, areal extent of snow cover, etc.)

The <u>practical</u> assessment of the resolution of ERTS imagery in terms of spectral and spatial characteristics, for hydrologic features of importance to the improved management of the NED reservoir system, was a major task of this investigation.

4.2.2 The ERTS-1 Imaging System

The ERTS-1 imaging system consists of the orbiting satellite with its sensor payload, the ground receiving, telemetry, and tracking stations; and data processing facility. It is a passive remote sensing system which receives and processes reflected solar radiation from the earth's surface. The radiation is received from a given surface area of the earth in discrete segments of time (period of exposure measured in fractions of a second) with a relatively long recurrence interval of 18 days. The ERTS imagery produced by the processing of reflected solar radiation for a given surface area can be thought of as instantaneous slices in time out of the continuous and changing view one would have from the vantage point of the satellite's position in space over the given surface area for the period of the mission. These 'slices' are arranged so as to occur under the optimum (overall) viewing conditions over the desired surface area of coverage compatible with the systematic and repetitive orbiting of the satellite. Over the NED region this process of 'slicing' began on 26 July 1972 at approximately 10 a.m. (EST) as ERTS passed over eastern Maine for the first time and has been repeated every 18 days since.

The major controllable factor in providing optimum viewing conditions of the earth's surface is the diurnal occurrence of solar illumination. The regularity and period of this has enabled the satellite orbital motion to be synchronized so as to permit the instantaneous views or slices to be taken under the most favorable daily solar illumination conditions. Major disruptive factors for which no orbital compensation has been made are irregularly occurring, surface obscuring atmospheric conditions such as haze or cloud cover; also seasonal and geographic variation in solar elevation angle. Other factors which influence viewing conditions, occurring at or near the surface will be discussed later in this report.

The areas covered in individual ERTS image frames are approximately 100 nautical miles square. New England and its coastal waters are covered in 30 frames taken on five orbital passes corresponding to five successive days (see figure 16), the sequential cycle repeating itself every 18 days.

Some portions of successive days' orbital paths overlap to provide a glimpse of 24-hour repeated coverage. This is an incidental feature of the system which nevertheless has allowed the observation of interesting snowmelt and ice melt phenomena in the course of this investigation. These studies in the overlap regions have provided us with some experimental experience of the usefulness of 24-hour repeat coverage for NED purposes. The width of the corridor corresponding to the portion of overlap of two orbital paths is latitude dependent, being greater for higher latitudes than lower ones. In the New England region the range is between approximately 39 miles at 40° latitude and 52 miles at 50° latitude.

Repeated imagery coverage of a given area is not necessarily in perfect registration. Image centers may vary crosstrack within a nominal ground distance of 25 miles and in-track within a nominal distance of 20 miles. This investigation has shown very little crosstrack variation and a comparatively large in-track variation which sometimes exceeded the nominal range of variation.

4.2.2.1 Sensors

The following sections briefly describe the RBV and the MSS systems aboard ERTS-1. Due to early failure of the power

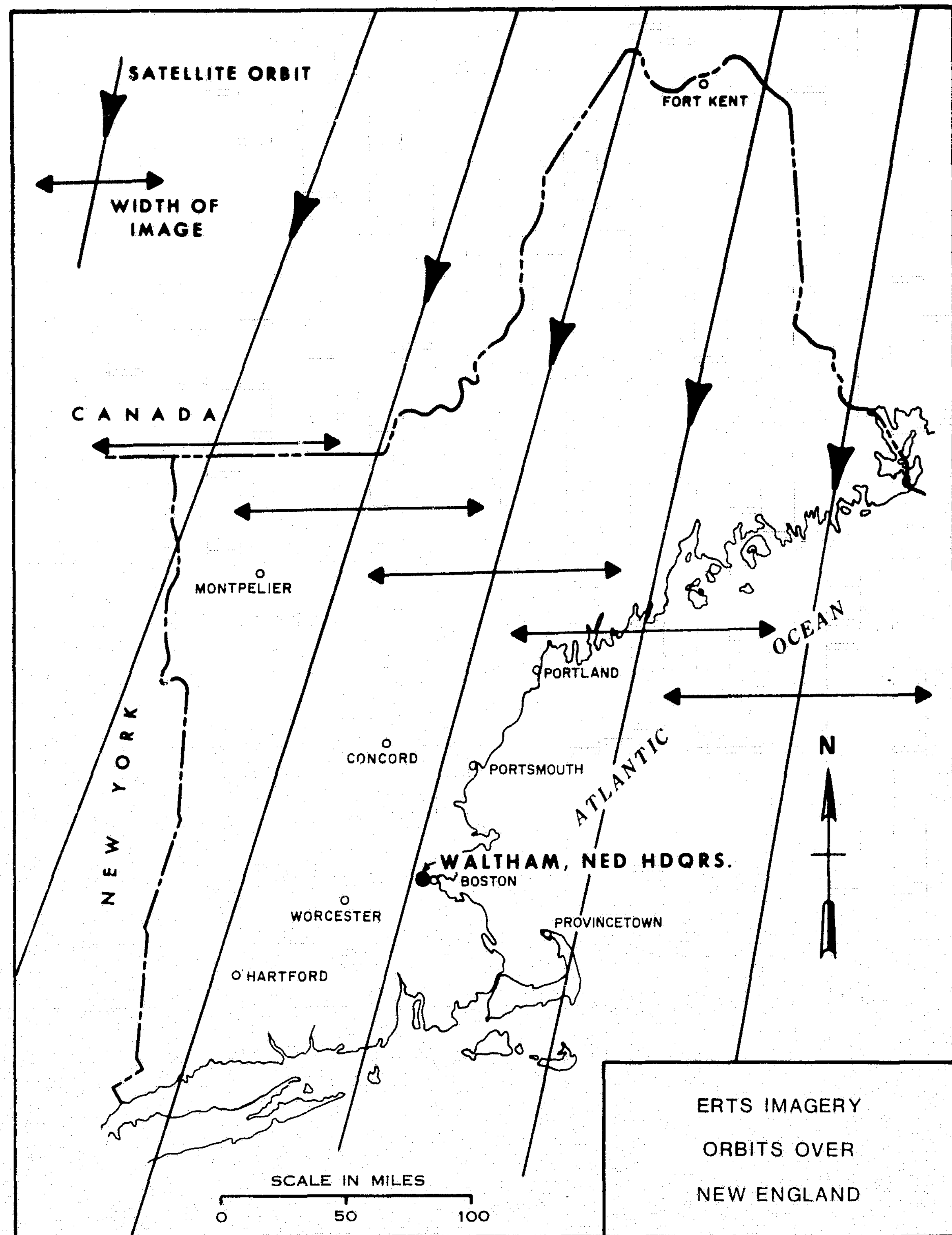


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FIG. 16

system of the RBV, nearly all products analyzed in this investigation are from the MSS.

4.2.2.1.1 Return Beam Vidicon Camera

The Return Beam Vidicon Camera (RBV) is essentially a high resolution TV system that contains three separate cameras operated in three spectral bands: blue-green .475 - .575 micrometers, green-yellow .580 - .680 micrometers, and red-IR .698 - .830 micrometers. The cameras view the same ground scene, 100 nautical miles on a side (see figure 17).

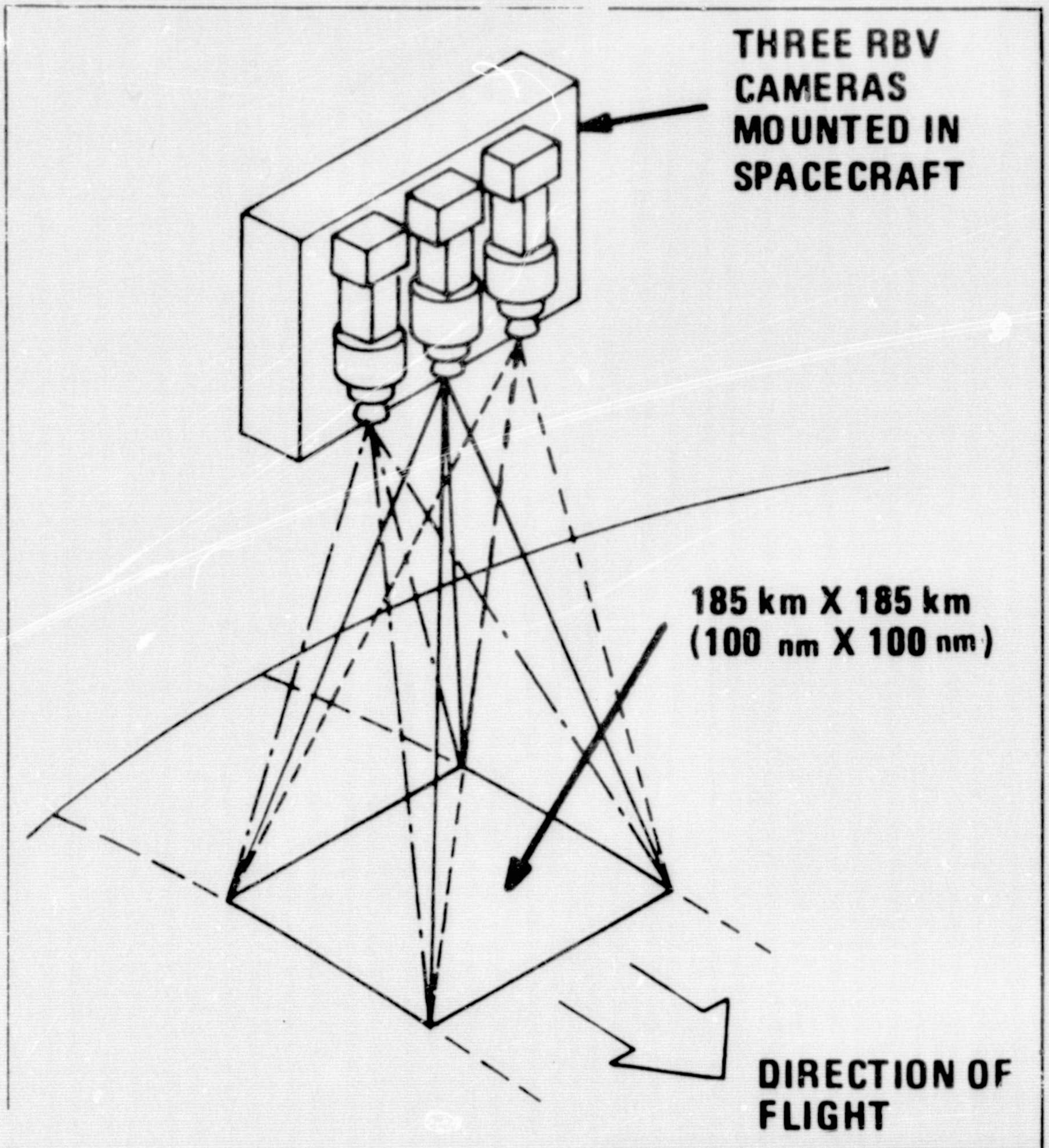
As the cameras are shuttered, images are stored on photo-sensitive surfaces on each vidicon tube. These are then scanned sequentially to produce video outputs which are transmitted directly to a ground receiving station if it is within range or stored temporarily on video tape to be transmitted when ERTS comes within the range of a ground station. To produce overlapping images on the ground along the direction of the ERTS motion, the cameras are shuttered every 25 seconds. At the ground the information received from the RBV is recorded on magnetic tape.

4.2.2.1.2 Multispectral Scanner

The Multispectral Scanner (MSS) is an optical-mechanical scanner consisting of an oscillating mirror which sweeps repeatedly across the nadir of the satellite orbital path reflecting image fragments onto photo detectors via an optical network (see figure 18). The width of the scanned strip is 100 nautical miles, identical to that for the RBV. Optical energy is sensed by the detectors simultaneously in four spectral bands: 0.5 - 0.6, 0.6 - 0.7, 0.7 - 0.8, 0.8 - 1.1 micrometers. During ground processing 100 x 100 nautical mile frames are constructed from the continuous strip. Figure 19 shows the same ERTS frame, taken over southwestern New England, in each of the four MSS spectral bands.

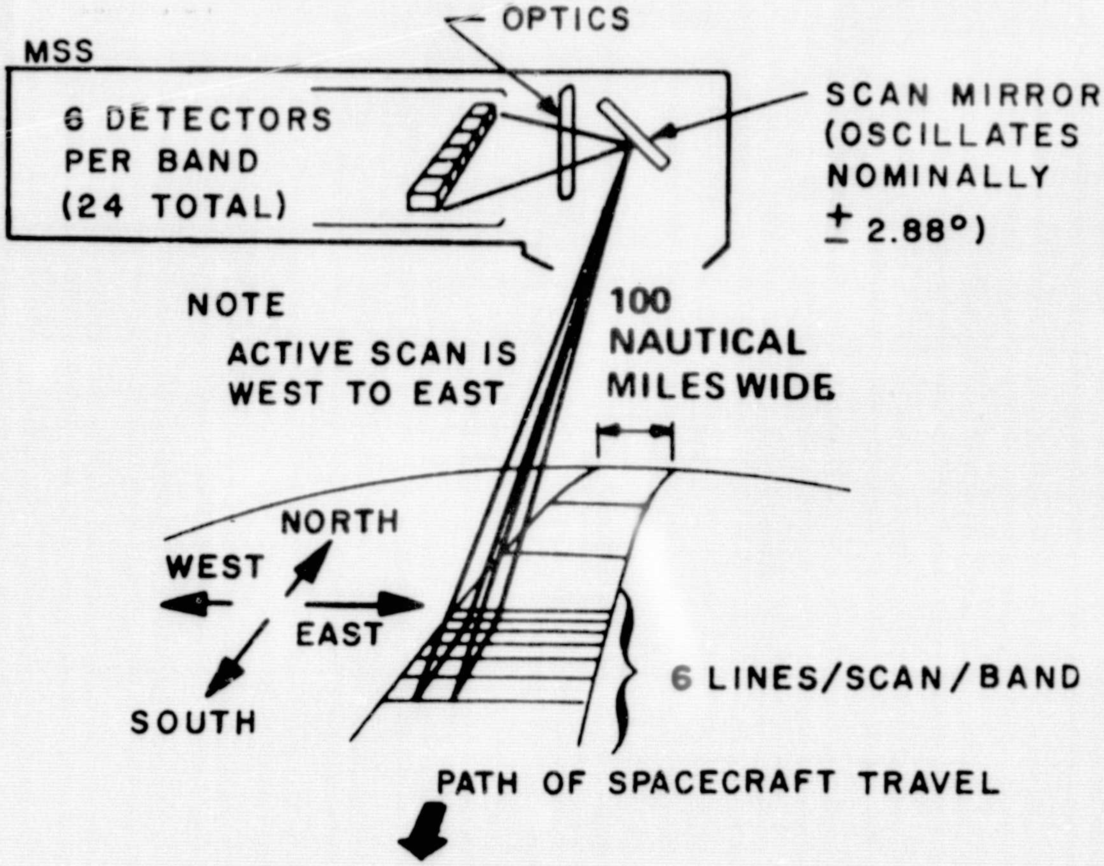
Because the MSS products were used most in this investigation, the operation and output of the MSS only and not the RBV is discussed at length in this report, as follows:

Reflected radiation from the earth's surface, plus that from the atmosphere is intercepted by the multispectral scanner mirror as it sweeps across the orbital path of the satellite. As the



THE RBV CAMERA SYSTEM

FIG. 17



THE MSS SYSTEM

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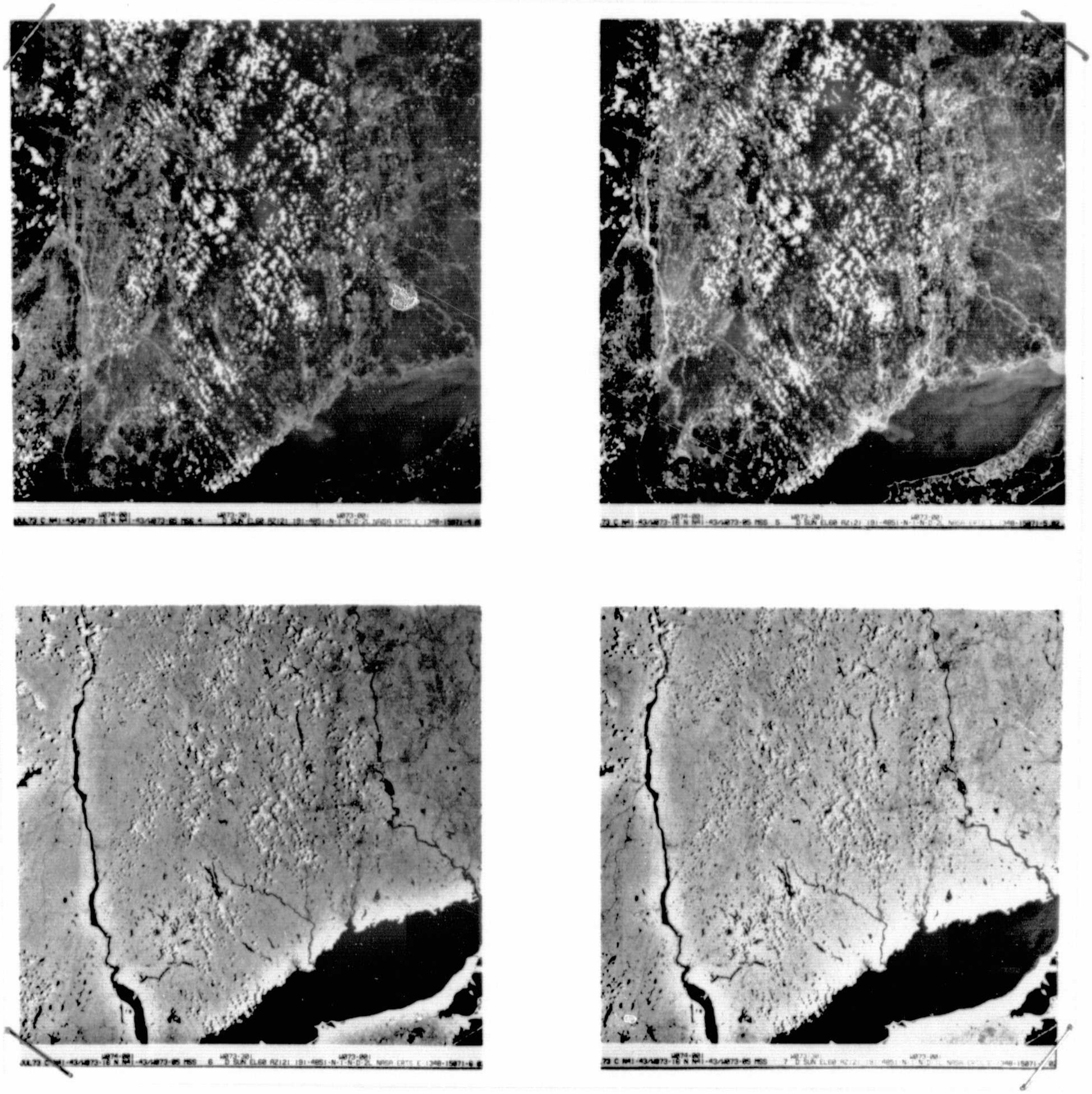
FIG. 18



ERTS MSS BANDS, SOUTHWESTERN NEW ENGLAND

FIG. 19

mirror sweeps crosstrack relative to the satellite orbit, the trace of the scan path on the earth's surface is influenced by the satellite motion and earth rotation. This produces a slightly skewed MSS image. The light received by the scanner is passed through a lens network and onto the optical fiber ends of a set of photo detectors. The light intercepted by a single fiber end passes through the fiber, through an optical filter, and then activates the light sensitive photo-electric detector which produces an electric signal. Each signal represents the average intensity of radiation in the bandwidth selected by the filter over the part of the projected surface image covered by the scanner that is reflected onto the optical fiber. The sweep of the scanner mirror and reflection of radiation onto the optical fibers is continuous and represents a horizontal or crosstrack path across the image scene. The path of each cross sweep of the scanner contains the parallel paths of six resolution elements in the four filtered spectral bands. As the mirror sweeps, the reflected light continuously strikes the 4 x 6 array of detectors. Six horizontal paths of light sweep over six horizontal rows of detectors striking each of four columns of detectors in sequence. Each of these four columns is equipped with filters of one of the four types corresponding to one of the four radiation bands.

The electric signal outputs from the detectors are continuous and therefore in analog form. A pulse-modulated multiplexer processes the signals by amplifying and converting them to digital form, by sampling the signal outputs from the detectors.

4.2.2.1.2.1 MSS Spatial Resolution

The distance covered along the path swept by the mirror in a single sampling period represents the width (crosstrack dimension) of a single resolution element or pixel. The length or in-track dimension of a pixel is represented by the width of the path of reflected radiation swept by the mirror which is intercepted by the detector. If the crosstrack dimension of a resolution element is based on the division of the total crosstrack image dimension by the number of samples from a detector taken in one complete scan path across the image scene; and, the in-track dimension of an element is based on the division of the total in-track image dimension by six times the number of mirror scan paths (six equal divisions of the in-track dimension of the mirror-reflected image corresponding to the six rows of detectors); the dimensions of resolution elements considered in this fashion form inteconnected elemental rectangles.

According to the information presented by NASA [3], the in-track dimension of a pixel and that of the corresponding elemental rectangle are practically the same since the ends of the optical fibers are rectangular, placed side by side, and together they intercept the full path width of light reflected by the scan mirror.

There is some doubt about the crosstrack dimension since an element represents only a sample from a continuous scan path. For the purposes of this investigation the term "pixel" will apply to the rectangular resolution element. With this in mind, the linear dimensions of a pixel so defined are as follows:

$$\text{Crosstrack} = \frac{\text{scene dimension}}{\text{no. of pixel intervals}} = \frac{100 \text{ n. mi.}}{3240} = 187 \text{ feet}$$

$$\text{In-track} = \frac{\text{scene dimension}}{\text{no. of pixel intervals}} = \frac{96.3 \text{ n. mi.}}{2340} = 250 \text{ feet}$$

For the computer compatible tapes the resolution model in this investigation will be the set of interconnected elemental rectangles, formed as outlined above, the full composite of which makes the image scene; each element representing a single pixel, and the corresponding elemental output sensor signal representing the average reflected radiation over the elemental area.

For the MSS photoproducts resolution is expressed in terms of standard optical models which depend on the characteristics of the photoproducts themselves. Resolution of photoproducts in this investigation was not considered in a quantitative sense other than to briefly note that system-corrected 9.5-inch photos (transparencies), received from NASA could be optically enlarged between 4 and 5 times before visual blurring was noticeable. This is to a certain degree, a user-dependent factor which places practical limits on the scale size of enlargements, overlays, maps, or other products produced from ERTS photos. Using available equipment, experience in this investigation has indicated a practical scale limitation of about 1:200,000 (enlargement of 5 times), for products of these types produced directly from ERTS photos.

4.2.2.1.2.2 MSS Spectral Resolution

For the MSS CCT imagery, radiance input power to

the sensor is represented by the output voltage count on a zero to 63 (64 level) scale. The 64 level MSS sensor voltage count is transformed into a 128 level count on the CCT's. For photo-products and on printouts made from CCT's, a 15 step (16 level) grey scale or output count is extracted from the 128 level count on the tapes.

The nominal error in output signal voltage or count from the sensor in representing the intensity of radiation input is shown in Table 5. Because of the relatively low value for this error shown for MSS CCT's which were the principal products used in the studies involving the quantification of imagery information, errors in the representation of radiation intensity were disregarded in this investigation and values of radiation intensity received from CCT's were not adjusted in ordinary work involving only one image scene. The only adjustments made were for images of the same scene taken at different times.

TABLE 5

NOMINAL ERROR IN OUTPUT SIGNAL VOLTAGE FROM MSS SENSOR

Product	Radiometric Error Percent Full Scale Sensor Count
System Corrected:	
70 mm.	5
9.5 inch	6
CCT	2
Precision Processed:	
9.5 inch	6
CCT	6

Values for ranges of radiometric errors in ERTS photoproducts are shown in Table F.2-1 of the ERTS Data Users Handbook[4] as a function of spatial frequency and system frequency

response. This is a consideration in performing densitometer measurements on photoproducts. A maximum error of 9 percent is shown for a spatial frequency of 40 cycles/mm. In a 9.5-inch ERTS photo, 40 cycles/mm. is the equivalent of approximately 92 feet of ground distance. Since this is only one-half the minimum pixel dimension as previously discussed, the largest possible upper limit of fundamental spatial frequency should be less than 40 cycles/mm. Therefore, the actual radiometric error should be less than 9 percent. In this investigation, possible radiometric errors were disregarded.

Several ERTS investigators are examining problems of applying scene radiance corrections to offset image degradation due to a variety of interferences and system limitations as well as the relating of radiance to reflectance. Corrections of these types were not applied in this investigation; however, in subsequent studies the fruits of such newly-acquired knowledge should be implemented wherever possible.

4.2.2.2 Imagery Products

ERTS imagery output consists of black-and-white and color products, and digital tapes. The black-and-white images come in 70 mm. and 9.5 x 9.5 inch sizes, the color in the 9.5 inch size only. Images are available as negative or positive transparencies or paper prints, but not necessarily all of these for each size or type. Digital output is available as either 7 track (556 bpi) or 9 track (800 bpi) computer compatible tapes (CCT's).

Two different types of processing can be applied to the ERTS output, for both the photographic and digital tape outputs. Bulk (or system corrected) processing refers to the "normal" imagery processing which contains the radiometric and initial spatial corrections introduced during the process of video tape to film conversion but not those corrections provided by the precision processing subsystem. Precision (or scene corrected) processing refers to all imagery that has received the extra radiometric and spatial corrections provided by the precision processing subsystem, including transformation into Universal Transverse Mercator coordinates.

In the NED investigation, the following five types of ERTS imagery products were used, all resulting from bulk (system

corrected) processing: black-and-white 70 mm. negative and positive transparencies, 9.5 x 9.5 inch positive transparencies and paper prints and 9 track, 800 bpi computer compatible tapes.

4.2.2.2.1 The Diazo Process

The diazo process of producing contact acetate color composites of ERTS scenes from 9.5-inch system corrected black-and-white transparencies was used in this study. With proper registration composite images were obtained for combinations of two or more MSS bands, each band being assigned a different color, such as cyan, magenta, red, etc. Varying degrees of saturation of a particular color in a given band represented varying degrees of reflectivity received in that band. Thus the composite product allowed one image to represent the information that would otherwise have to be obtained from each of the constituent bands separately.

4.2.3 Imagery Studies - Photo Interpretation

4.2.3.1 Surface Waters - Location and Coverage, Especially During Flood and Low Flow Periods

Excluding such interfering factors as haze and cloud cover, and neglecting the effects of icing during cold weather, surface waters usually appear uniformly dark in the ERTS near IR bands (MSS 6 and 7), almost completely absorbing the incident radiation corresponding to these ranges of wavelength. There appears to be less response to the effects of bottom reflectance or suspended or dissolved materials in the water in these bands as compared with bands MSS 4 and 5. For this reason, the best delineation of surface waters is generally afforded by the MSS bands 6 and 7.

Areas where vegetative ground cover has been stripped away are also highly absorptive of near IR radiation, and appear dark in MSS bands 6 and 7. This tends to mask the discrimination of surface waters located in such areas in these bands. This effect tends to be more pronounced in band MSS-7 than in MSS-6. In general water still appears dark in bands MSS-4 and MSS-5 compared with most other features while areas with stripped away ground cover appear to exhibit relatively high light densities. In such areas, the discrimination between water and land may be better in bands MSS-4 and 5 than in MSS 6 and 7. Because of this, the best overall visual discrimination between land and water may be in a color composite combining several bands.

Only the larger rivers in the New England region are clearly and distinctly displayed on ERTS imagery. These rivers include the Connecticut, Merrimack, Saint John, Androscoggin, Allagash, Aroostook, Kennebec, Penobscot, Housatonic, Thames River estuary and the Providence River estuary. In most cases the delineation of surface water boundaries can be made to within a single pixel in the near IR bands (MSS-6 and 7); however, there are some exceptions as in cases where boundaries are indistinct because water is adjacent to marsh or areas covered with aquatic vegetation. Thus, it was concluded that a river must be at least 2 pixels wide in order to be easily recognized.

Mapping of flooded areas using ERTS imagery is generally limited to those that are well displayed at scales down to 1:200,000 which is the limit of enlarging ERTS photo imagery (using standard photo equipment) before significant blurring occurs. This tends to exclude all except the very largest flood plains in the NED region.

For most river basins under jurisdiction of the New England Division, peak flood conditions usually occur during periods of limited visibility and atmospheric interference by cloud cover. Lag times between peak precipitation and peak runoff tend to be relatively short for all but the largest river basins. The lower Connecticut River which may crest several days after the occurrence of peak flood conditions in the upper portion, provides the best opportunity for peak flood conditions to be recorded by satellite imagery in the NED region. Enough time is probably available in most cases for cloud cover to clear off before the Connecticut River crests downstream. Until such time as atmospheric conditions can be compensated for, satellite imaging will continue to be severely limited for flood observations in New England. Also, while the 18-day cycle of ERTS coverage has allowed the observation of several serious floods during the course of this study, more frequent imaging would be essential for an operational system designed to provide information on all floods that occur, perhaps on the order of daily or even twice daily.

An interesting effect showing promise is the study of ERTS imagery over previously flooded areas. Locations which have been inundated seem to retain their absorptivity to near IR radiation for periods as much as several months after the floodwaters have receded. Figure 20 is a diazo color composite of a

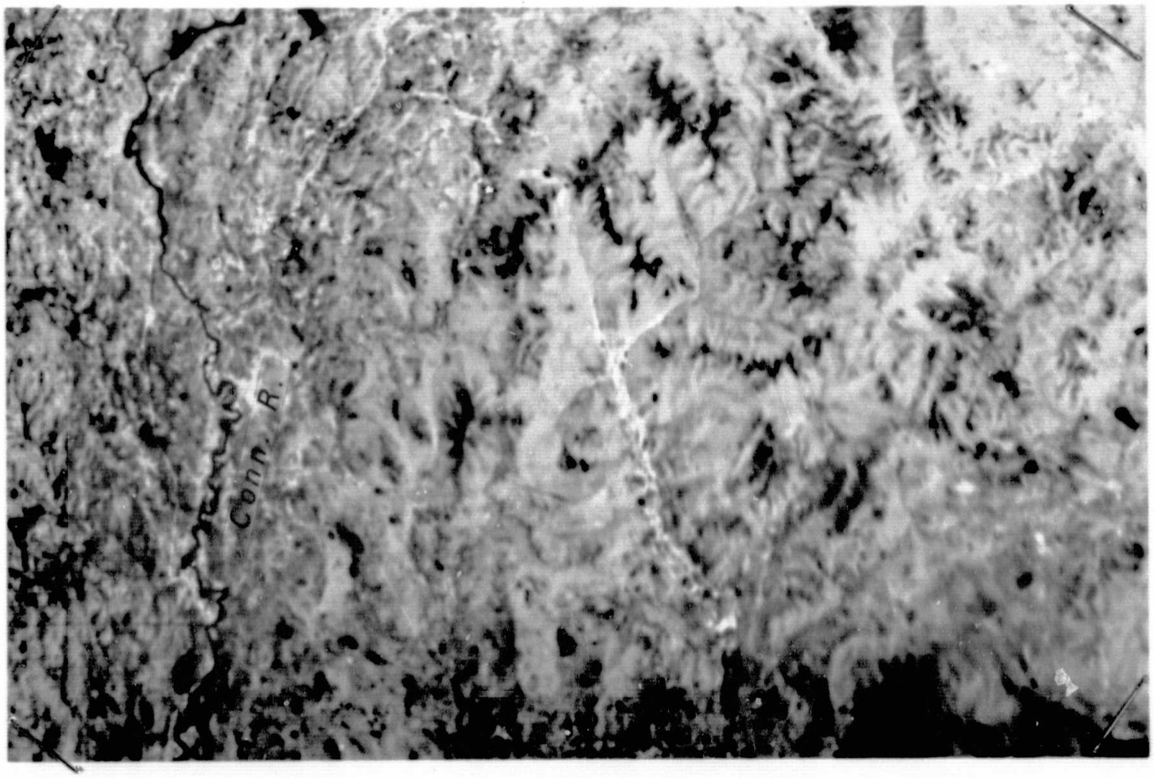
reach of the upper Connecticut River taken on 24 July 1973, three weeks after the flooding occurred. We believe the light blue areas along the river represent some type of residual effect upon the absorptivity as a result of the flooding. This may be due to either soil moisture or vegetative conditions.

4.2.3.2 Icing Conditions on Rivers, Lakes, Reservoirs and Around Hurricane Barriers

The icing of larger lakes, rivers and reservoirs is readily apparent on ERTS 9.5-inch images, scale 1:1,000,000. Ice conditions have been well displayed on major NED rivers - Connecticut, Merrimack, Saint John, Allagash, Aroostook, Penobscot, Kennebec and Androscoggin. However, in the case of smaller rivers, the same problem occurs with observation of ice as observation of rivers alone. The dimensions of resolution elements become large relative to those of the object being observed and a clear pattern cannot be formed. In general, rivers must be at least 2 pixels wide before ice can be reliably detected. Haze and cloud cover may also limit observations of ice.

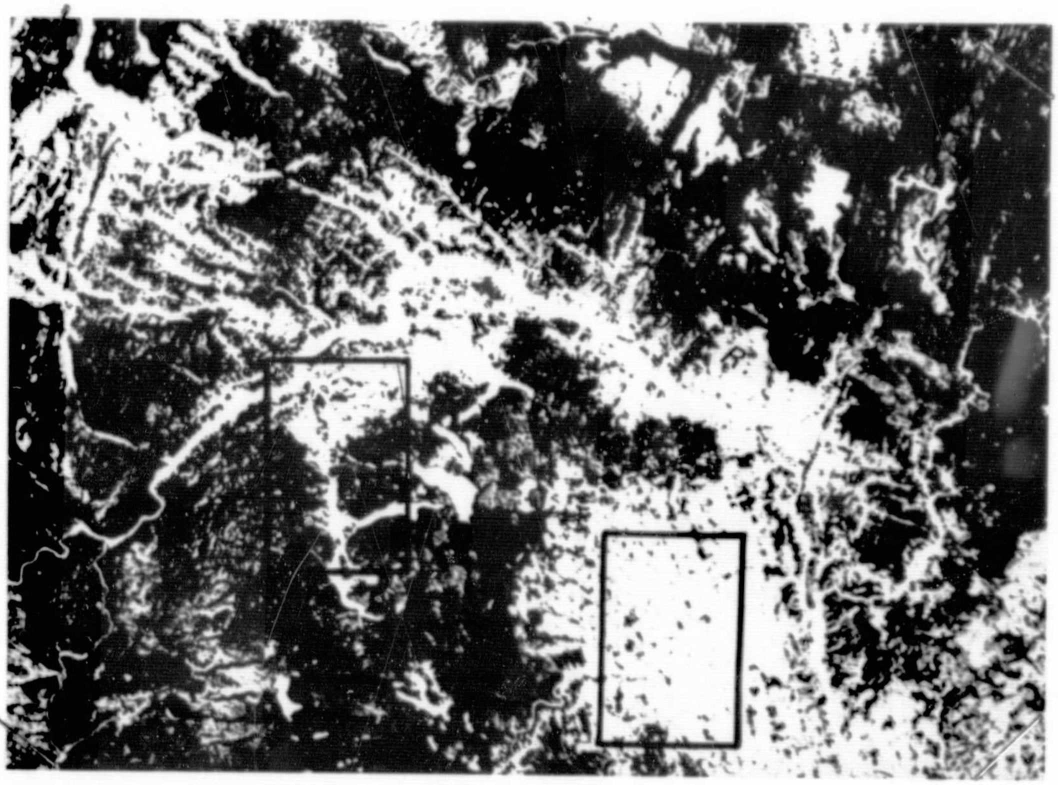
Based on our experience to date for larger rivers, lakes and reservoirs, the study of ERTS imagery can verify icing conditions and specify the areal extent of ice cover. However, ice thickness or liquid water equivalency using ERTS imagery could not be specified. Reflectivity differences in the imagery over ice suggest that some correlation may be possible between varying reflectivities and ice condition (i.e., well frozen or melting). Icing around the NED hurricane barriers was not studied in detail because of inadequate imagery spatial resolution.

From an operational viewpoint, repeated ERTS-type satellite coverage on a once-a-day basis could effectively monitor the icing conditions of large rivers. In the case of the Saint John River, Maine, shown in both winter and summer in figure 21, the spring thaw and breakup of ice has in the past caused serious problems of jamming, backing-up of water and then breaking and releasing floodwaters. The flood of late April 1974 at Fort Kent, Maine is a recent example. This particular river is large enough for such conditions to be detectable by ERTS if it were available on a once-a-day basis. The effective monitoring of these conditions which often occur in remote areas could provide valuable lead time in preparing for flood conditions and in possibly taking remedial

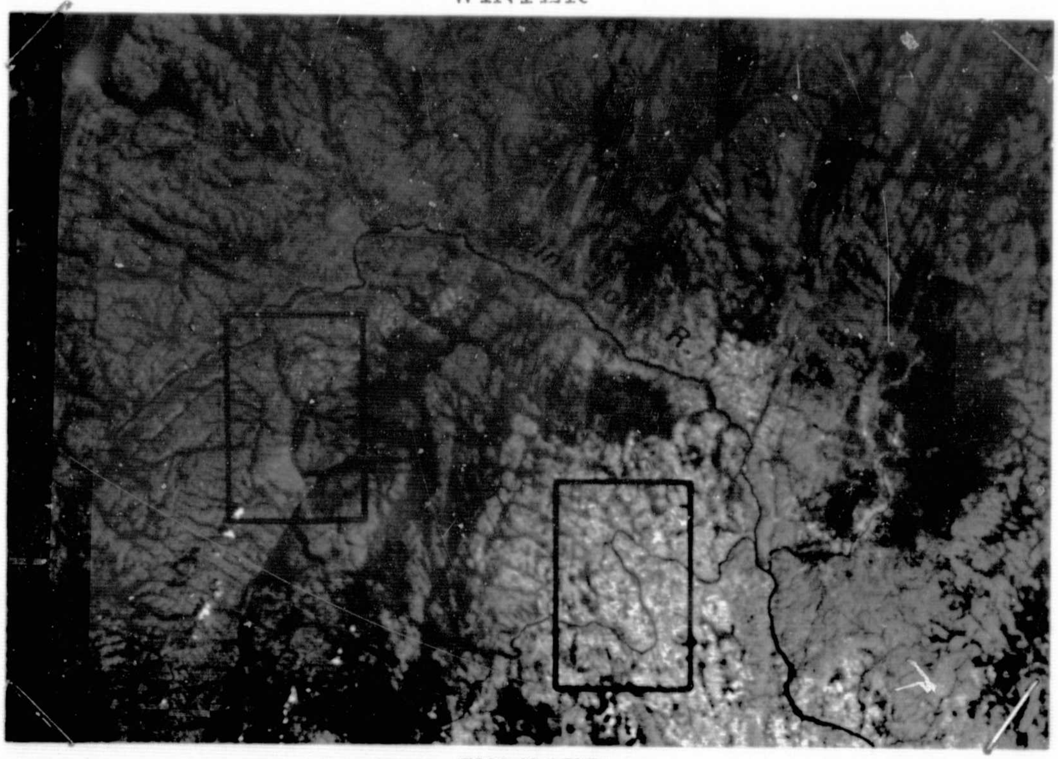


ERTS COMPOSITE IMAGE, CONNECTICUT RIVER, THREE WEEKS AFTER A FLOOD

FIG. 20



WINTER



SUMMER

ERTS COMPOSITE IMAGES, SAINT JOHN RIVER, MAINE
(LEFT HAND BOX - EAGLE LAKE AND THE FISH RIVER;
RIGHT HAND BOX - AROOSTOOK RIVER)

FIG. 21

action, such as breaking up of ice jams by means of explosives before they have a chance to impound excessive and potentially dangerous quantities of water.

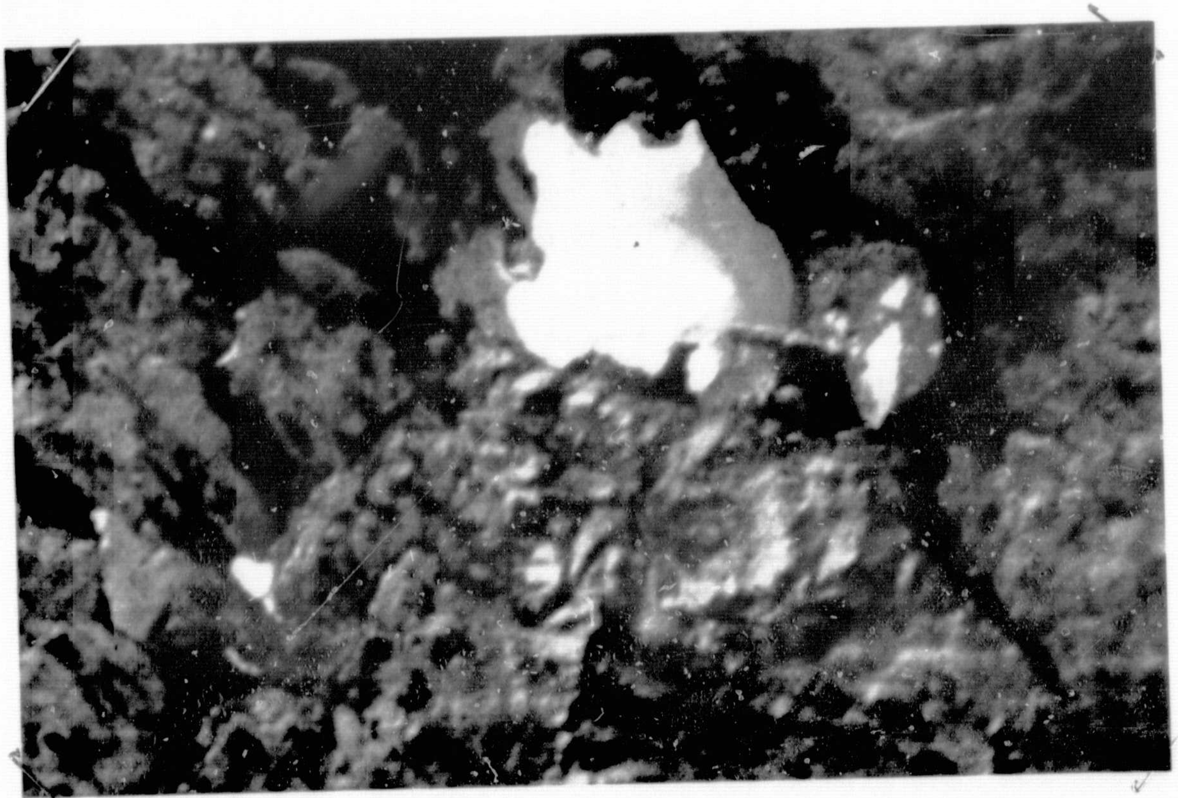
A glimpse of the type of changes that could be detectable by daily coverage is shown in figure 22. This is a color composite picture of a portion of Lake Winnipesaukee, New Hampshire using the overlapping sections of imagery from two successive days in midwinter. The ice which melted considerably from one day to the next appears as the red colored region. Areas that had ice on both days appear as white in the picture, while those with open water on both days are black.

4.2.3.3 Turbidity and Sedimentation in Lakes and Reservoirs

Indications of surface water quality characteristics are recognizable in ERTS imagery. Figure 23 is a diazo print showing the sediment discharge plume of the Connecticut River into Long Island Sound after a flood. The imagery itself does not specify particular water quality parameters unless these are documented and correlate with ground-truth information. It can indicate possible differences in water quality among the various portions of a surface water body by the display of patterns formed by corresponding variations in spectral properties. In the case of figure 23 the pattern is large enough to be easily recognized. In the case of inland lakes, rivers, and reservoirs in New England, detection is more difficult due to limited spatial resolution. Detection of relative differences in water quality are not possible for most rivers in New England because of their limited sizes and the limited spatial resolution capability of ERTS.

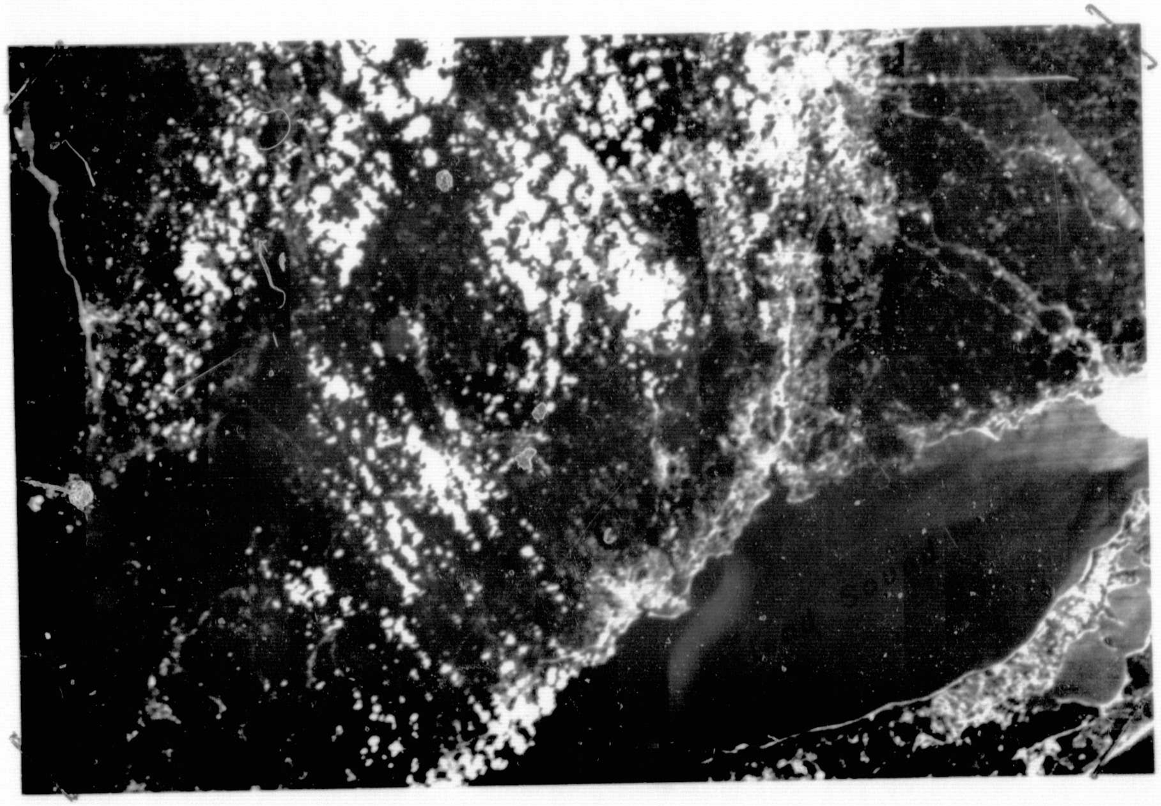
Even in well-mixed situations where the quality tends to be homogeneous in a given water body and differential surface patterns are not formed, some information can still be provided pertaining to water quality conditions. The spectral properties of known polluted or suspensoid-laden waters can be compared with those of other water bodies whereby differences can be detected. Silt and algae-laden waters tend to exhibit relatively high light densities in band MSS-4 and to a lesser extent in band MSS-5.

Differences in bottom reflectance caused by variation in light attenuation as a result of varying water depth and quality, and by varying spectral properties of the bottom sediments



ERTS COMPOSITE, LAKE WINNIPESAUKEE, NEW HAMPSHIRE FROM OVERLAPPING SECTIONS OF TWO SUCCESSIVE IMAGERY PASSES TO SHOW MELTING OF ICE

FIG. 22



ERTS COMPOSITE IMAGE, SEDIMENT DISCHARGE PLUME
OF THE CONNECTICUT RIVER AFTER A FLOOD

FIG. 23

also manifest themselves in the imagery. The effects of water quality and bottom reflectance can be so intermingled that it is often difficult to distinguish them without supportive ground truth information.

The spectral aspects of surface waters can also be affected by interfering factors such as atmospheric haze and scatter, as well as glint from waves and ripples. The relatively wide-band spectral resolution and restricted spectral range of ERTS imagery is also a limiting factor in identification of water quality characteristics. More variations could probably be detected with narrower bands and an extended spectral range covering at least the blue visible and thermal IR portions. Although some impressive examples of water quality variations have been detected by ERTS, it should be noted that a number of instances of known differences have not been revealed on the imagery. Further study and relating of imagery to ground truth is required to establish the reason for these apparent anomalies.

The time intervals associated with changes in water quality characteristics vary according to the type of water body and the characteristic being considered. In the case of eutrophication in lakes and reservoirs, the changes are generally seasonal whereas the temporary silting of flooded streams and rivers may last only a day. Some pollution patterns may appear relatively unchanged over long periods of time, while others may change from day to day or even over shorter intervals. The 18-day cycle of coverage by ERTS is generally capable of detecting only longer term and seasonal changes on a regular basis. The short term post flood sediment plume siltation shown in figure 23 was an opportune coverage, only fortuitously obtained within the 18-day cycle.

If ERTS-type imagery provided at least daily coverage, effective monitoring of post flood silting of larger rivers, reservoirs and lakes should be possible as well as many short term pollution episodes. Improved spatial resolution could extend the effective coverage to smaller bodies of surface water.

4.2.3.4 Location and Extent of Snow Cover

In general, NED winter snow cover patterns appear as high light density regions in ERTS imagery in comparison to the low density noncovered regions. It is necessary to view the entire snow pattern which in many cases may cover more than one image frame

in the New England region, in order to view the scene with the proper perspective and contrast relative to a nonsnow covered background. Figure 24 is a diazo print of midwinter snow cover in western New England. The snow covered areas appear as the high light density regions dominating the upper portion of the picture. Even though there are many shadowed and dark regions within the overall snow pattern due to obscuration by vegetative cover and to low winter sun angle upon hills and mountains, the overall pattern separating snow covered from noncovered regions is recognizable. Viewing conditions are greatly improved in late winter and early spring due to better solar illumination and shadow reduction. Low sun elevation appears to be the more severe obscuring factor than that from the direct masking effects of vegetative cover. This has been verified by the fact that in the early spring the snow cover over heavily forested areas is highly visible in the ERTS imagery.

Superimposed on the imaged snow cover pattern in figure 24 are the snow isohyetal lines as determined from ground truth snow surveys. As can be easily seen, the imagery shows the snow/no snow line much more accurately than the snow survey data. The imagery, however, does not give any clue to snow depth or water content, the two parameters that are obtained in the surveys. For reservoir regulation purposes the water content of the snowpack is the essential information to be obtained, especially for areas with a considerable accumulation. The exact demarcation of the snow/no snow line is of little or no use for reservoir regulation as the snow water content in these areas is negligible. Thus, the potential of ERTS-type imagery with the present sensor package, to provide snow information equivalent to that obtained from snow courses for reservoir regulation purposes is all but nonexistent. Finally, if ERTS could provide information on snow water content, the 18-day cycle of coverage would be too long for operational usefulness. Weekly coverage would be necessary.

4.2.3.4.1 Contoocook Basin Snowmelt Study

An intriguing opportunity to assess the potential of ERTS imagery for providing information concerning snowmelt was afforded to this investigation in the spring of 1973. A considerable amount of snowmelt occurred over the Contoocook River basin in New Hampshire between 6 and 7 April 1973. On both days the area was imaged by ERTS as it was located in the overlap region between two successive orbits. The images, shown in figure 25, were

ERTS COMPOSITE IMAGE, MIDWINTER SNOW COVER IN WESTERN NEW ENGLAND

FIG. 24

APRIL 7
10 A.M.

APRIL 6
10 A.M.

TWO SUCCESSIVE ERTS COMPOSITE IMAGES SHOWING DEPLETION OF SNOW COVER OVER THE CONTOOCOOK RIVER BASIN, N.H. - APRIL 6-7, 1973

FIG. 25

taken at approximately 10 a.m. on the respective days. The Contoocook River basin is outlined and labelled 'B'.

Based on detailed study of the images and corresponding hydrometeorological data from ground truth sources [5], the following information would have been provided by ERTS had daily repetitive coverage been available in an operational system:

a. The ERTS imagery added to the body of evidence tending to indicate that the high levels of runoff over the period 6 to 9 April 1973 were significantly contributed to by meltwater.

b. ERTS imagery provided confirmation that snow covered most of the basin on 6 April 1973 at 10 a.m. and fixed the time during which most of the snow cover disappeared as the 24-hour period from 10 a.m. 6 April to 10 a.m. 7 April 1973.

c. ERTS imagery provided information about snow cover distribution changes over areas too distant from regular daily measurement stations for meaningful extrapolation, especially at high elevations along the basin divide where accumulations appeared to remain on 7 April after melting had taken place at other locations.

In summary, based on the implications of the 6 and 7 April ERTS coverage of the Contoocook, it can be concluded that some useful information on snowmelt might be extractable for Reservoir Control Center purposes if data on a daily basis were available.

4.2.3.5 Location and Extent of Excessive Precipitation Accumulation

Although no specific instances were studied, it is likely that excessive precipitation accumulation on the ground could be detected by ERTS imagery in cases where pooling at a scale large enough to be resolvable by ERTS would occur. All of the same imagery attributes and limitations described in section 4.2.3.1 would likely apply here.

4.2.3.6 Tidal Levels and Flooding at or Near Hurricane Barriers

Only cursory looks at the ERTS imagery have been made of tidal levels and flooding at the NED hurricane barriers. This kind of information must be obtained in real time to be operationally useful

to NED. Also data must be obtained during storm situations, at night, and at sufficient ground resolution to be operationally useful. None of these needs is satisfied by ERTS imagery.

4.2.3.7 Soil Moisture Conditions

Various investigators have reported on the discrimination of soil moisture using various spectral discrimination techniques. Our studies in this area are limited to the overall studies of flooding and post-flooding situations (see section 4.2.3.1). Using diazo color composites, it appears possible to delineate areas of inundation even months after inundation occurred. Further study is required.

4.2.4 Imagery Studies - Computer-Oriented

Some technical aspects of the imagery are briefly outlined in the following sections. Concepts such as scene radiance, transmittance, image registration, boundary determination, scale, etc. are introduced with the view of providing the reader an adequate background for assessing the computer-oriented analyses of the ERTS imagery and for comparisons with photo-interpretation techniques.

4.2.4.1 Scene Radiance

The radiation detected by an ERTS sensor consists of that reflected by the earth's atmosphere and surface features minus the portion lost in transmission through atmospheric media. This can be represented in the following manner.

$$N(\Theta,\lambda) = \frac{H(\Theta,\lambda)}{\pi} R(\lambda)\tau(\lambda) + N_A(\Theta,\lambda)$$

$N(\Theta,\lambda)$ = Radiance received by sensor

Θ = Sun angle

λ = Spectral wavelength (band)

$H(\Theta,\lambda)$ = Irradiance of ground scene due both to direct or indirect sunlight

$R(\lambda)$ = Reflectivity of scene

$\tau(\lambda)$ = Atmospheric transmittance from ground scene to sensor

$N_A(\Theta,\lambda)$ = Radiance of atmosphere only, viewed from space

The desired information concerning surface features is contained in the R term. In relating imagery radiance data to surface reflectance on an absolute basis, factors H, Θ, τ and N_A would all have to be accounted for in relating R to N for a particular λ.

In relating image data within a given scene taken at a given time on a relative basis, N_A, H and τ may or may not show significant variance, depending mainly on atmospheric conditions. Experience gained in the investigation has shown that in relating image data within a given scene taken at a given time on a relative basis, the variables H, τ, and N_A may sometimes be considered to remain constant without too much error in the assumption under generally clear, cold and haze-free atmospheric conditions; whereas they would be expected to vary widely among images of the same scene taken at different times, especially when different seasons are involved. The fact that H does vary over a given image scene is readily noticed when the individual images composing an in-track strip mosaic of successive scenes taken in a single satellite pass are compared. Near the border region of two adjacent images, terrain is illuminated with the sun in front of the sensor as the north side image is taken with the satellite moving southward. The same region is illuminated with the sun behind the sensor as the south side image is taken. In the same latitudes in the southern hemisphere, the effect would be just the opposite. Because the part of the albedo in the direction of the sun tends to be the most illuminated in the image, and because the satellite tends to be more in line with the path of direct surface reflectance when the satellite and sun are positioned on either side of a particular piece of terrain than on the same side, the southern edge of the north side image appears more illuminated and to exhibit a higher level of scene radiance than the adjacent northern edge of the south side image. For a single image scene, therefore, H varies and appears to increase from north to south. This might be compensated for in processing the imagery so as to cause an opposite effect in the

final product, thus balancing the distribution of irradiance across the image scene. This was not judged to be necessary for the purposes of this investigation, but would be appropriate if a high level of accuracy in determining reflectance levels is required. Although H is stated to be a function of Θ and λ, it should also be considered a function of the position of a particular ground location in relation to the position of the satellite and that of the sun. Θ depends only on the position of the ground location relative to the sun; however, H may vary as the location of the satellite with respect to the ground position changes while Θ remains the same. Thus, the term $H(\Theta,\lambda)$ is more a representation of the average irradiance over the entire image and not for a particular location within the image. The change in H across a particular image scene should theoretically be most pronounced during the winter months when Θ values are lowest thus producing larger gradients of ΔH across an image scene. Experience has shown however that due to low Θ values and consequential lack of overall irradiance, $H(\Theta,\lambda)$, the darkness of winter scenes tends to obscure ΔH values across an image so as to become less noticeable than in spring, summer, and autumn scenes in which the overall irradiance is much greater.

In this investigation, image data were related to reflectance on a relative basis only. The criterion used in accounting for the effects of H, Υ, and N_A over an image scene was to assume them as being constant over areas in the imagery devoid of cloud cover, haze, or other gross atmospheric interferences, and related by the formula for $N(\Theta,\lambda)$ as previously given. Since terms H and N_A would be constant for a given band, or range of λ: $H(\Theta,\lambda) = H(\lambda)$; $N_A(\Theta,\lambda) = N_A(\lambda)$ and $N(\Theta,\lambda) = N(\lambda)$. An absolute rather than relative basis would be necessary for temporal comparisons of imagery. This could be done if the mode of sensor operation were accounted for in the case of CCT-produced imagery; however, for photo products, variations in photo processing would also have to be considered. The problem of comparing images taken at different times over the same scene, without reverting to an absolute scale, can be partially circumvented in the case of photo products by reprocessing them in a manner which sets the radiance levels indicated by the photos to the same relative scale. Thus, in the case of two such images, N_1 and N_2; $N_1 = aN_2 + b$ where a + b are constant for all values of N_1 and N_2 over locations where R is known to remain constant with time, provided N_A can be properly accounted for and that the H and Υ values are reasonably constant over the scene covered by a particular image. In the case of

CCT-produced imagery, in accordance with the formula for $N(\lambda)$, a and b can be found by performing a linear regression computation of values of radiance at locations(control areas) in the images where the reflectance properties, $R(\lambda)$ are known to remain constant with time. In this investigation the problem was partially solved by setting the count level or grey-scale step the same in both images for objects which, because of their nature, are known to have the same reflectance properties in both images. This is essentially what was done in adjusting the grey scales on photographs by reprinting transparencies and appropriately adjusting exposure time.

Another observed problem in relating radiance, N, to reflectance, R, concerns local or near-surface interference which occurs when certain ground features are obscured by others. This was encountered in the cases of interference of the observation of snow cover by overlying trees and vegetation, the observation of soil conditions by vegetative cover, observation of parts of surface water bodies by overlying vegetation, and the observation of reservoir, lake, river, estuary and coastal bottoms by the overlying water. The radiance of the interfered-with phenomenon can be accounted for as:

$$N(\theta,\lambda) = \frac{H(\theta,\lambda)}{\pi} R(\lambda)\tau(\lambda)\, I(\lambda) + N_A(\theta,\lambda)$$

where $I(\lambda)$ = transmittance of the interfering media

4.2.4.2 Image Registration

The registration of different bands of the same image is not considered to be, nor has it been found to be, a problem with either photo products or computer-oriented imagery. The handling of this is a built-in feature of NASA's data processing system. The registration of images of a given scene taken at different times, on the other hand does present problems to the investigator. For photo products, registration can be performed manually by overlaying photo transparencies taken at different times and matching up image objects visually until a suitable fit is obtained. This has been done successfully in this investigation and others in displaying hydrological changes which have occurred in the interim periods between the taking of images of selected scenes. The registration of computer images taken at different times could be

automated in concept if the images being registered were completely free of distortions, by selecting stable objects which give point locations such as highway intersections, airport runway intersections, identifiable structures, etc. which could be used as image control points and suitably indexed. The index of signal positions on the CCT's could then be adjusted to fit the index system of the objects once they have been identified. The registration might also be accomplished by using the geographic location of the image center as given in the annotation block and then adjusting the signal index of a given image to an index system based on geographic location (meridional and latitudinal coordinates). Either of the two methods could be used to check the other.

These registration techniques are complicated by image distortion caused by several factors. These include errors commonly encountered in aerial photogrammetry such as radial distortion, due to differences in parallax angles among surface features of different heights, plus those which are an inherent part of the ERTS system.

In this investigation manual registration of temporally different images of a given area has revealed the following:

a. Excellent registration over small sections of individual frames.

b. Deterioration of accuracy with distance from image centers and with size of area registered.

Considerable further study is still necessary to perfect the methods of registering computer imagery.

4.2.4.3 Boundary Determination

Boundaries such as water-land interface, ice-water interface and snow-lines are shown in imagery as the boundary between areas of different radiance intensity or contrast in a particular spectral band. In color-composite images, boundaries are also indicated by areas of different color as well. Image-enhancement techniques increase the differences in contrast or color and thereby accentuate boundaries in imagery. Several ERTS investigators are currently examining a variety of enhancement techniques for both photo products and CCT's ranging from rather simple to

fairly complex procedures. In this investigation the delineation of boundaries in both photo and CCT imagery was based on simple and somewhat arbitrary criteria.

In CCT imagery, boundaries were generally designated by a given cutoff level of grey scale intensity which separated one object or class of objects from others. A given location, represented by a pixel, for example, can be classified according to its spectral signature as represented by the following vector: (x_1, x_2, x_3, x_4) where x_i is a given level of intensity as represented by grey scale values ranging from 0 to 15 and i, in the case of MSS imagery, would designate one of the four spectral bands MSS-4, 5, 6 or 7. It may happen that two bands or even one particular band can, in some cases, designate a class of objects as well as if all four bands together were used. This appears to be true in many cases of the ability of band MSS-7 to designate surface waters. The occurrence of surface water is most frequent in the lowest radiance levels of band 7. The mean or most frequent level of the grey scale, or some other parameter, may then be used to designate the cutoff level. The problem is to determine what levels simultaneously are most inclusive of the given objects and exclusive of others. Surface waters appear to be most exclusively represented in the near IR bands (MSS 6 and 7) at the lowest levels of reflectance, but their occasional occurrence may extend to higher levels.

A criteria being used in this investigation to determine the extent to which the reflectance of an object or a particular class of objects in a particular band occurs within a specified range of reflectance levels is to compute the mean, mode, and standard deviation of the frequency of occurrence of the object or class of objects in an imagery sample for various levels of reflectance. The implication is that the smaller the standard deviation, the smaller the range of reflectance levels and the more exclusive the representation of the given class of objects by the specified range of values. If the mode differs with the mean by a significant amount, the implication is that the set of values is skewed or has more than one peak and that the objects very likely have not been correctly identified in the imagery samples or properly classified as a set with similar reflectance properties.

The objects that most interfere with the detection of water in band 7 by virtue of their proximity to water in having similar reflection characteristics in this band appear to be cloud shadows,

those caused by mountainous or rugged terrain, and other features, urban and paved surfaces being the most predominant. This does not include the masking effect of clouds themselves or other direct interference but only that caused by objects with similar reflectance properties. The problem of overlap of occurrences between different classes of objects in a particular band may be solved by considering one or more other bands where the occurrences appear at more widely separated grey scale levels, thus providing contrasts of color as well as intensity. Urban pavement, for example, appears to occur most frequently at considerably higher levels of reflectance than water in bands MSS-4 and 5 than in MSS-7. For this problem, the operating variable might be considered to be the two-dimensional vector representing grey scale levels in MSS-5 and 7. For other problems the complete four-dimensional vector, (x_1, x_2, x_3, x_4) representing bands MSS-4, 5, 6 and 7 could be used to designate the optimum exclusive-inclusive vector space occupied by a given class of objects. Finally, a boundary may lie anywhere within the ground space covered by a resolution element, and perhaps within a choice of several elements depending on the separability of occurrence of classes of objects by virtue of their reflectance properties in a given spectral band or combination of spectral bands.

In this investigation the foregoing considerations were made when manually defining a land-water boundary from a set of alpha-numeric symbol clusters on a computer printout, with the ultimate goal being to be able to automate the boundary determination process and incorporate these considerations into computer software. In this investigation, a cutoff value such as grey level value is chosen for delineation of a given feature, such as water, depending on the particular image under investigation and on simple statistical tests and comparisons with ground truth or map information to designate the presence of water. All values of grey scale level beyond the chosen cutoff point are then assumed to represent the feature for the purpose of performing computer computations. This is in effect, a density slicing procedure which uses reflectance as the only criterion for boundary selection. More advanced pattern recognition techniques involving shape and other optical properties can also be applied along with density slicing to boundary or interface determination, but have not been applied in this investigation.

If full advantage could be taken of all information in

an image to enable the determination of a boundary to within the dimension of one MSS resolution element, the maximum error in terms of ground distance would be about $\pm$90 feet. For the method of density slicing, referred to in the previous paragraph, without scene radiance corrections and without any attempt at more advanced pattern recognition techniques, the maximum possible error is greater. How much greater dependson factors such as atmospheric interference and interference by objects within the image with similar reflectance characteristics, as previously discussed.

4.2.4.3.1 Snowlines

Snowlines are natural boundaries which in this investigation have presented a special problem. The problem is one of interference, $I(\lambda)$, as briefly discussed previously in dealing with that aspect of scene radiance, N, which is written as follows:

$$N(\Theta,\lambda) = \frac{H(\Theta,\lambda)}{\pi} R(\lambda) \Upsilon(\lambda) I(\lambda) + N_A(\Theta,\lambda)$$

where symbols N, N_A, H, R, Υ, I, Θ, and λ are all defined in the same way as before. The interference, I, is caused mainly by trees and vegetative cover in the New England region and is not generally uniform over an image scene, tending to exhibit considerable variability over large areas. Even in heavily forested areas with snow cover, however, the scene radiance was found to be more intense than in nonsnow covered areas. This is because areas with heavy interference seem to have a greater degree of irradiance of the ground scene, H due to reflected and perhaps re-reflected direct and indirect sunlight off the surface of the snow beneath the forest or vegetative canopy. The boundary between snow covered and nonsnow covered ground as indicated on imagery does not, therefore, appear to be as much a difference in reflective intensities as in the case of land vs. water, where a fairly distinct boundary usually occurs; rather it is a difference in irradiance or illumination between these areas. The boundary here is less distinct and more blurred than in the case of land vs. water, and the likely positional error in fixing it is assumed to be greater.

Snow occurs over wide areas in the NED region during winter months, often covering many image scenes put together. For most purposes, however, using computer-oriented imagery on this scale involves unjustifiably large amounts of data. Photo imagery is more convenient and less costly to work with. Overlays

of snowlines were often drawn by hand directly from imagery. A more systematic method involves density slicing by designating a cutoff level of radiation intensity corresponding to snow or non-snow covered areas. A densitometer is particularly suited for this type of work since the aperture opening is large enough to average out the effects of high spatial frequencies corresponding to differences in radiation intensity among resolution-size elements. A computer could perform the averaging operation also, but this would entail the handling of all the basic data on the CCT's and would therefore be a more costly operation.

4.2.4.3.2 Ice-Water Interface

Another boundary situation is that of the ice-water interface. The boundary between liquid water and ice usually appears distinctive, and occurs over relatively small areas such as river channels, reservoirs, lakes, ponds, etc. where the examination of icing effects is important. Operational examination of icing phenomena using computer-oriented imagery is likely to be useful and desirable.

4.2.4.3.3 Surface Water Identification

The identification of individual bodies of surface waters such as lakes, reservoirs, or rivers as well as other similar features is a fundamental part of image interpretation. This activity can be carried out visually and is dependent on the ability and background knowledge of an observer to recognize and associate image objects with correctly-identified ground objects. A human observer may perform these activities routinely and without being conscious or concerned over the details of the procedures of making associations. The bulk of the work of this investigation involved image interpretation of this type. These procedures must be considered in detail, however, if one desires to automate the interpretation process, using computer imagery.

In the identification, inventory and classification of surface waters using ERTS imagery, the proper utilization of CCT data can mean a savings of time and effort that would otherwise be required in manually observing, measuring and accounting for these image features. It can also lead to a more systematic and accurate procedure using the inherent advantages of the computer to sort, store, and perform operations on vast amounts of

information in a short amount of time. An approach to doing this has been considered in this investigation and can be briefly summarized as follows: scan image data, identify surface waters, recognize and sort out individual water bodies and distinguish them from each other, perform operations over each image of a surface water body area on an individual basis, number and classify according to size or order-of-magnitude, and extract other pertinent information concerning these waters. This involves computer pattern recognition techniques, whereby the computer "learns" from the human operator to identify and distinguish between various image patterns and progressively becomes less and less dependent on the operator.

4.2.4.3.4 Boundary Fixation and Overlay Problems

Part of the problem of fixing a boundary whether on CCT-produced imagery or photo products, for the purpose of classifying image areas and performing operations within these areas, is that of image registration. If it involves only one image of a scene taken at a particular time the problem is more simple than that of applying a boundary to a set of registered images of a particular scene taken at different times.

The criteria for determining and setting a particular boundary location may require information derived wholly and exclusively from the imagery data as with land-water and ice-water interfaces, and snowlines. In many cases, however, the criteria require information which is partially derived from imagery data and partially derived from other sources. This latter category may include political boundaries such as state, county, or district lines, or geographic coordinates, which are referenced to fixed ground locations such as state or regional coordinate systems or the Mercator global system which is referenced to the intersection of the equator and the north-south meridian passing through Greenwich, England. It may also include survey-determined boundaries involving ground measurements such as contour lines or watershed boundaries. The information contained on maps and charts may be shown relative to fixed ground objects which can be readily identified and registered with their counterparts on ERTS imagery; or registered by referencing the map data and the imagery data to the same coordinate system.

One boundary fixation problem of special interest is

that of setting a watershed boundary. It was found in this investigation that in mountainous regions where breaks in terrain are noticeable in ERTS imagery, the image might supply all the information required. In the case where terrain is flat and image texture is uniform and continuous, it is nearly impossible to determine criteria for setting watershed boundaries from the information supplied by imagery alone.

The setting of boundaries in this investigation was accomplished in some cases by means of manually-produced overlays on both photo products and computer imagery produced from CCT data. The error in manually setting a boundary depends on such factors as contrast, resolution and scene radiance, and also includes the working scale, instrumental precision, and the human factor of skill or care in drafting, drawing, engraving, or whatever technique is employed to physically scribe the boundary or produce an overlay. If only image data are involved in determining criteria for setting a boundary the factors just specified may represent a fairly complete list. If the criteria depend on information derived from other sources, the errors depending on these factors, which may include map or survey precision, interpolation and map or map overlay production, should also be accounted for. Error in overlay production E can be represented in simple terms by the following:

$$E = E(Res, IP, H, MP, I, S)$$

Res = resolution/contrast

IP = instrumental precision factor

H = human factor (skill or lack of it)

MP = map precision (if map data are involved)

I = interpolation

S = scale

where the dimensional units are in ground distance.

The function E might take the following form:

$$E = \frac{(e_{Res} + e_{IP} + e_H + e_{MP} + e_I)}{KS}$$

where K = constant

In this case E is inversely proportional to the scale, S, and the e values are assumed independent of S and of each other. These assumptions may not necessarily be valid in all instances.

4.2.4.4 Scale

The scale or dimension of ground objects in terms of dimensions of their imagery counterparts is a persistent problem in the case of ERTS imagery. The scale of any imagery or map product is rendered satisfactory or unsatisfactory depending on what the product is to be used for. Also, a usable scale generally depends on the size of objects being dealt with and the convenient working dimensions of the user which can in turn depend on such factors as good drafting or drawing size for making overlays or superimposing notations or boundaries, convenient sizes for filing, storage, reproduction, display, etc. Producing simple dimensional enlargements or contractions of images from one scale to another for various purposes has its limitations. The major one is image resolution which has already been discussed in some detail. In the case of photo products, enlargement will eventually produce blurring at the interface of an object and its background. We have judged that the practical limit of first-generation scale enlargement of ERTS photos is about 1:200,000. Other investigators on this project have indicated the capability of enlarging ERTS photos to greater scales.

The 1:24,000 scale used for U.S. Geological Survey quadrangle maps with 10-foot contour intervals is an adequate scale for a wide variety of water resources planning, investigation and engineering work. For detailed project or construction plans, still larger scales are generally necessary. Experience gained in using ERTS imagery in the NED region in the course of this investigation suggests that the capability of producing enlargements of selected portions of ERTS photos to scales in the order of 1:24,000, as used in USGS quadrangle maps would be most desirable. Because of the order-of-magnitude of size of most surface waters in the NED region, such a scale is convenient to work with and would facilitate direct comparisons between ERTS imagery and existing quadrangle map data. Also at this scale significant changes in such parameters as surface water area would be well displayed.

CCT processing provides a means of enlarging ERTS imagery to higher magnification. Besides providing a means of

quantifying scene radiance values over elemental areas, the CCT printout imagery composed of alpha numeric symbols spaced on a rectangular format provides better feature representation at a larger scale than would an enlargement of a photo to the same scale. In making overlay comparisons with map or gound truth data, the boundaries of surface water bodies, for example, have been properly delineated within the pattern of resolution elements making up the CCT-produced imagery. If the CCT images are to be printed on standard computer printout sheets, format distortions must be removed if these are to accurately represent the surface dimensions of ground objects in their true proportions. The corrections that must be applied are either approximately a 30 percent contraction in the in-track direction, or a 40 percent expansion in the cross-track direction on CCT printouts of MSS imagery.

The limitations on the uses of ERTS imagery due to scale to which the imagery can be enlarged are fundamentally related to the problem of limited resolution. This is in fact the basic limitation of the ERTS system for many purposes. For ERTS imagery there is, therefore, a minimum detectable object dimension. This limitation on the size of detectable dimension also limits the accuracy of measurement. In an absolute sense the error in determining, hence measuring a dimension is the same for all objects, large and small. In a relative sense, however, the same absolute magnitude of error is greater for small objects than for larger ones. The possible relative accuracy of measurement (percent accuracy) is least therefore for the minimum detectable object dimensions, and improves as the sizes of objects become larger.

The criteria used in this investigation for setting the minimum detectable object dimension are based on the automation of procedures for classifying objects according to radiation density and not on other pattern recognition criteria. The minimum size determined this way is conservative and is considered to be that size necessary to guarantee that at least one pixel projection onto the earth's surface will fall completely within the object's area. In the case of surface water, it would be the minimum size or dimension necessary to ensure that at least one pixel projection would be exclusively over water. For objects of smaller size than that of the projected pixel, the indicated intensity of reflectance will be due to radiation reflected in part from the object, e.g., water, and in part from its background, e.g., land. This presence of reflected background light interferes with the object's

detection as far as radiance density is concerned and therefore obscures it in relation to its background. Even though an object may still be recognizable, the true contrast or intensity level representative of the object will not manifest itself in the imagery then, unless a pixel projection lies completely within the area occupied by the object, e.g., completely over water. The minimum dimensions at which this can theoretically possibly occur are those of a single pixel. The probability that a pixel would fall exclusively over water on a body with the same dimensions as the pixel projection itself is however practically nil. On the other hand, an object of two pixel equivalents in linear dimension will always contain at least one full pixel projection exclusively over it in that dimension. If this criterion is used for determining the minimum sized ERTS detectable object, the following conclusions can be drawn:

> Minimum possible width W of river that will always be detectable as water:
>
> W = 2 pixel lengths = 374 feet (crosstrack),
> 500 feet (in-track)
>
> Minimum possible areal size A of a water body (pond) that would always be detectable as water:
>
> A = 374 x 500 (2 x 2 pixel block) = 187,000 feet^2 = 4.3 acres.

If objects are to be definable at the minimum sizes, the integrity of individual pixels must be maintained during image processing. This requires the processing of individual signal bits on CCT's in terms of the spatial representation of pixels, on a one-to-one basis. This type of work requires the computer processing of CCT's. For the study of large dimensional features however, as already discussed in the case of snow cover, over large or regional areas, where absolute accuracy need not be as great in order to obtain the same level of relative accuracy of measurement as for smaller features or objects such as inland surface waters, the processing of individual pixels does not have to be performed on a one-to-one basis with bits of signal data on CCT's in terms of spatial dimensions, thus allowing for considerable data reduction.

4.2.4.5 Surface Water Characteristics: Dunham Pond

A study was performed to determine how well the

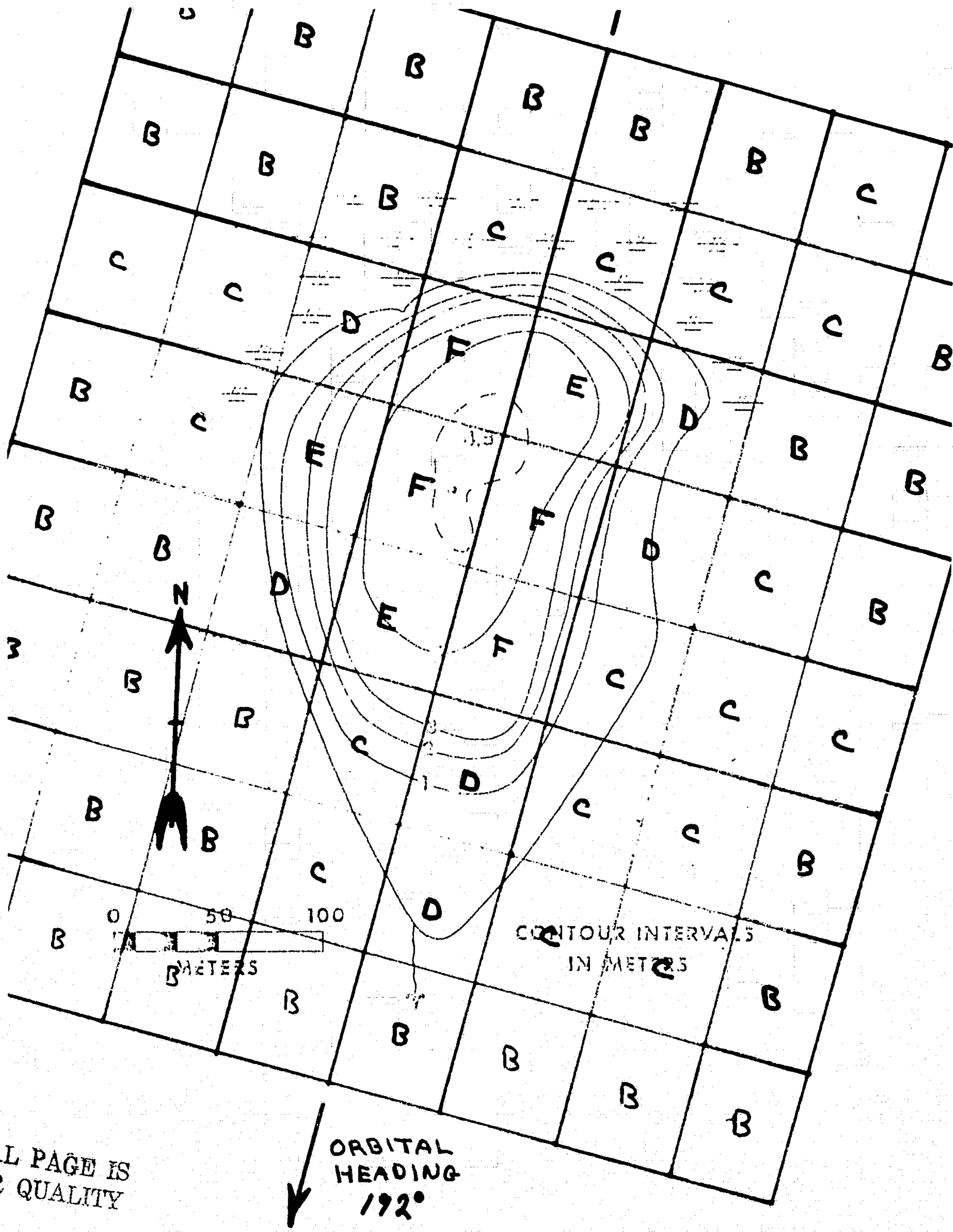
digitized spectral density levels in CCT imagery correspond to both the location and depth of surface waters. Ground data for correlation with the ERTS imagery was taken at Dunham Pond, a 7-acre body of surface water in Connecticut with horizontal dimensions of approximately 1,100 x 600 feet. Figure 26 shows a reproduction of a CCT printout of the Dunham Pond area in MSS band 7 overlain with a surveyed map of the pond and its depth contours.

The symbols represent the density levels on a 16-step grey scale as 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F ranging from the highest to the lowest reflectance level. The scene shown is rather dark in band 7 and uses only the lowest five density levels. Correlation coefficient comparisons between reflectance and presence of surface water yielded $r = 0.974$ and between reflectance and water depth, $r = 0.949$.

It is likely that the relationship between reflectance and presence of surface water can be extended to all surface waters. That between reflectance and depth is certainly another question however, since detection of depth variations is dependent upon such factors as turbidity and other water quality parameters, as well as bottom reflectance, etc. The case of Dunham Pond provides hope that in certain waters, ERTS can detect differences in depth, however considerably more study is necessary to determine if and how this could be extended to the general case, perhaps using all the ERTS spectral bands , or other wave bands not available aboard ERTS.

4.2.4.6 Flood of July 1973 at Franklin Falls Dam, New Hampshire

A comparison was made of ERTS imagery of Franklin Falls reservoir area, New Hampshire, filled to approximately two-thirds capacity immediately after the flood of July 1973, with the post-flood unfilled condition of late August 1973 to delineate and compute surface areas of the flooded locations. Due to partial cloud cover immediately after the flood the entire surface area of the reservoir waters could not be accurately computed, so that the results as far as the original intent and purpose was concerned were inconclusive. An interesting phenomenon occurred, however, when the comparison between the two digital printouts of images taken immediately after the flood and again 8 weeks later was made. Even though the floodwaters had long since receded, much of the previously



DUNHAM POND, CONN.- SURVEYED MAP COMPARED TO CCT MSS BAND 7 PRINTOUT

FIG. 26

inundated area still appeared at a low density level, not quite as low as that of the surface water in the adjacent pool, but lower than that of the surrounding forested terrain. The 29 August 1973 image indicated that the properties of the terrain which was flooded in early July had been altered by the July flood, possibly due to damage of vegetative cover. Areal computations were easily made by simply summing the elements forming the pattern representing the seemingly damaged area and multiplying by the ground area of a pixel. The total area of this pattern around the Franklin Falls reservoir area on 29 August 1973 computed in this manner was approximately 1,950 acres. More detailed studies are necessary to further explore this phenomenon in the ERTS imagery.

4.2.4.7 Man-Computer Interactive Approach

Work has been accomplished in the area of computational algorithms aimed at producing fast, efficient programs to display useful information relating to ERTS imagery analysis. This work was primarily supported by a National Science Foundation grant aimed at developing novel concepts and techniques for imagery data management. The work was carried out by Prof. Y. T. Chien, University of Connecticut, and his graduate students during the academic year 1973-74, in conjunction with the present project.[6,7] The man-computer interaction approach to imagery analysis must pay special attention to the problem of putting various information in a form suitable for computer display and human observation. The information to be displayed usually involves several (more than two) channels such as the 4 spectral bands of the ERTS imagery. Thus, our problem is to transform data of high-dimensionality into two-dimensional space ready for display. This type of transformation must satisfy the following requirements:

a. The intrinsic characteristics of the imagery must be preserved.

b. It must be computationally fast to avoid any excessive idle time on the part of human observers while engaging in man-machine interactive analysis.

Several classes of display-oriented transformation methods have been studied in relation to the ERTS imagery. By combining several MSS bands of information we have examined the possibility of delineating various classes of hydrological features

(water, land, etc.) in an interactive environment. A limited experiment with a section of the Cape Cod Canal, Massachusetts and its adjacent land has been carried out to test the transformation methods developed. Results indicate that:

a. With the aid of a computer display, the human operator can play a direct and immediate role in selecting the MSS bands that will describe certain hydrological features in the most informative way.

b. Speedy display and user's interaction of information may be achieved by putting transformation algorithms in a recursive structure. This will allow the user to apply the algorithms to various sections of the image for analysis without introducing excessive calculations.

We have developed a number of computational techniques, operational programs, and utility subroutines that are designed to provide computer-oriented means for the interactive analysis of ERTS imagery. Due to the late arrival of tapes and extensive work in printing parts of scenes for human study, we did not progress very far in building a truly interactive pattern recognition system to facilitate the analysis of ERTS imagery. Given sufficient resources, a reliable, interactive system may be established which maintains as a data base information obtained from many MSS tapes, then uses this information to predict occurrences similar to those stored, upon input of image information on a real time basis in an operational situation. This development of a truly operational system would involve the relating of ground truth information about hydrologic events (i.e., snow conditions, flooding, rain data, etc.) to imagery entered into the computer, over a period of time to "train" the pattern recognition system to recognize and analyze future hydrologic events to be presented to it.

The specific objective of such a system would be for the identification and analysis of real time hydrologic events that are considered relevant to NED flood control operations, in an interactive environment, probably with a Cathode Ray Tube and light pen to allow the user to 'communicate' with the computer and outline the nature of the information desired in any given instance. There is no doubt that for many parameters a properly operating man-interactive system could save substantial amounts of time in the increasingly complex decision making processes involved with flood control reservoir regulation.

4.2.5 Imagery/DCS Interaction Studies

The present investigation has focused mainly on acquiring the practical experience in setting up and running the ERTS DCS experiment at NED and in interpreting the ERTS imagery within the context of a daily operational Reservoir Control Center. The DCS and imagery studies have been conducted as parallel but supportive studies at the outset. Our objective was to first acquire maximum "real-life" experience with each type of ERTS data. Having obtained a sampling of actual experience in real NED situations using DCS data and ERTS imagery, we are now better able to develop a strategy for overall coordination of all NED data sources.

Several general conclusions can be made at this time regarding the interreactions among the ERTS DCS, ERTS imagery and AHRRN for NED operational purposes.

a. Real time or near real time data acquisition and management systems are required for effective coordination of reservoir regulation activities. The longest time delay at present is in the ERTS imagery system (measured in weeks). ERTS DCS data are received in near real time (measured in hours). NED is dependent on real time data acquisition by the AHRRN (measured in minutes). To be most operationally useful in coordination with information obtained from the other sources, the time lag of ERTS imagery should be about comparable with that for the DCS and the AHRRN. The latter two would provide ground truth for better interpretation of the former. Real time imagery acquisition implies a capability similar to that of the NOAA APT system.

b. Management/hydrologic models that can input the DCS/imagery data are required. Generation of such models is a major undertaking. NED is moving in this direction with the development and upcoming testing of the flood forecasting and routing computer program in the Merrimack River basin in cooperation with the Corps of Engineers Hydrologic Engineering Center.

c. "Quasi-operational" or "demonstration" experience over a wide range of flood-and reservoir-management situations must be acquired before an overall system becomes operational.

d. Operational readiness of NED system components including management and operational personnel and hardware

and software is required. Management decisions are required at each step to move from the quasi-operational to the operational phase.

e. Studies and reevaluations must continue indefinitely, keeping pace with advancing technological and cost information to see that the system is composed of the most economically feasible and technically useful combination of modes of point data relay and imagery data acquisition as well as data processing techniques.

4.2.6 Conclusions and Recommendations

4.2.6.1 Imagery Studies - Photo Interpretation

Using standard photo equipment, experience in this investigation has indicated that ERTS photo imagery may be enlarged about five times, or to a scale of 1:200,000. This is sufficient for only rather large scale or gross feature patterns to be represented with the accuracy necessary for flood control reservoir regulation purposes.

Only the larger rivers in New England are clearly displayed on the imagery. Mapping of floods is restricted to gross overflow of waters from New England's rivers. However, since flooding may occur at any time, the ERTS 18-day cycle is insufficient for regular monitoring of New England floods. Daily or even twice daily coverage would likely be necessary. Even with this, clouds associated with flood producing storms often obscure flooding from the view of the satellite at those times when imagery acquisition would be most critically needed. An interesting effect worthy of further investigation is the apparent distinguishability on ERTS imagery of areas previously, but no longer flooded, for periods up to at least several months after flood recession.

Ice is readily detectable on ERTS imagery, as is the ice-open water interface. ERTS imagery could lead to early detection of ice jams on the larger New England rivers. Daily coverage during the cold months of the year could provide a useful supplement to other means of monitoring the development of ice jams, especially in remote areas.

Indications of varying water quality characteristics

are recognizable in ERTS imagery. Again, information is normally obtainable only from larger water bodies. So many different parameters are involved in water quality, and in such varying degrees- often intermingled with each other, that much study still remains before ERTS imagery could relate specific imagery responses to specific ground truth information. Also, interference from atmospheric haze and scatter, glint from waves and ripples and bottom reflectance can be especially difficult to compensate for. Finally, ERTS imagery bands neglect some of the spectrally important wave lengths for water quality detection. Nevertheless, where ground truth can be confidently correlated to the imagery, some changing water quality patterns might be usefully displayed in repetitive imagery coverage. The 18-day cycle could effectively monitor these if changes were occurring over a similar or longer interval. Many water quality changes are of this nature. For shorter term episodes such as post-flood silting of rivers, daily coverage would likely be essential.

Winter snow cover patterns are readily obtainable with excellent accuracy from ERTS imagery, however, the imagery provides only snow location, not depth or water equivalent which is the operationally important parameter. If ERTS could provide information on snow water content, the 18-day cycle of coverage would be too long for operational usefulness. Weekly coverage would be necessary.

A look at 24-hour snowmelt as detected in the imagery over a region of overlap between two successive days' orbits showed some promise for the use of snow cover information for short term application. This would be especially useful if imagery on a daily basis were available, thus allowing a certain degree of educated extrapolation to be performed on the water equivalent measurements obtained by ground surveys on a weekly basis.

Excessive precipitation accumulation probably could be detected by ERTS imagery in instances where pooling at a scale large enough to be resolvable by ERTS would occur.

Tidal levels and flooding at or near hurricane barriers were briefly studied. This type of information must be obtained in real time. Also the data must be obtained during storm situations, at night and at sufficient ground resolution to be

operationally useful. None of these needs is satisfied by the present ERTS system.

The only specific look at possible moisture detection in the soil by ERTS imagery was made in association with flood and post flood conditions. As reported earlier in the Conclusions and Recommendations, ERTS imagery appears able to distinguish areas previously, but no longer flooded, for periods up to at least several months after flood recession. Whether this is a soil moisture or a vegetation-related phenomenon is open to further study, however.

The diazo process of producing contact acetate color composites of ERTS scenes was frequently used in the Photo Interpretation portion of this ERTS investigation. It was found to be quite useful in that the composite product of several bands allowed one image to represent the information that would otherwise have to be obtained from each of the constituent bands separately.

4.2.6.2 Imagery Studies - Computer Oriented

The ERTS Computer Compatible Tapes (CCT's) provide data in digital form thus allowing high speed processing of the imagery information. This can be important since for most operational applications the mass of data in an ERTS image may tend to be too unwieldy for timely analysis by photo interpretive techniques. Computer processing provides the means of quantifying scene radiance values over elemental areas, and thus the CCT printout imagery, composed of alpha-numeric symbols spaced on a rectangular format, also allows for better feature representation at a larger scale than would an enlargement of a photo to the same scale. For computer imagery, it was decided that the minimum detectable object dimension was related to pixel dimensions and to be that size necessary to guarantee that at least one pixel projection onto the earth's surface will fall completely within the object's area. Thus, the minimum possible width of a river that will always be detectable as water = 2 pixel lengths = 374 feet (crosstrack) or 500 feet (in-track); the minimum possible areal size of a water body (pond) that would be always detectable as water = 187,000 feet^2 or 4.3 acres.

A study of surface water characteristics at a small pond (7 acres) in Connecticut yielded a correlation between imagery reflectance and presence of surface water of $r = 0.974$ and between

reflectance and water depth of $r = 0.949$. While the relationship between reflectance and presence of surface water can undoubtedly be extended to all surface waters, that between reflectance and depth probably cannot, since detection of depth variations is in turn dependent on such variable factors as turbidity and other water quality parameters, as well as bottom reflectance, etc. The particular case studied here nevertheless provides hope that in certain waters, ERTS can detect differences in depth, however considerably more study is necessary to determine if and how this could be extended to the general case, perhaps using all the ERTS spectral bands, or other wave bands not available aboard ERTS.

4.2.6.2.1 Man-Computer Interactive Approach

Work has been performed in the development of a man/computer interactive system, with a Cathode Ray Tube (CRT) and light pen, that could allow real time analysis and utilization of ERTS computer imagery for important water resource management decisions. A number of computational techniques, operational programs, and utility subroutines have been developed to provide computer oriented means for the interactive analysis of ERTS imagery. Due to the late arrival of tapes and extensive work required in printing parts of scenes for study, we did not progress very far in building a truly interactive pattern recognition system to facilitate the analysis of ERTS imagery. As part of our ERTS-B follow-on investigation, we hope to continue development of a reliable interactive system which maintains as a data base information obtained from many MSS tapes, then uses this information to predict occurrences similar to those stored, upon input of image information on a real time basis in an operational situation.

4.2.6.3 Imagery/DCS Interaction Studies

The coordinated use of all data available to a real time operational Reservoir Control Center should include the interaction between real time imagery and point data sources such as the ERTS DCS for ground truth. Before this interaction situation can become a reality it would be necessary to provide some means of real time relay of ERTS imagery to an operational RCC. Even prior to such a situation, however, a useful interaction may take place as the management/hydrologic models that can input DCS/imagery data pass through various stages of development and testing.

4.2.6.4 General

4.2.6.4.1 Spatial Resolution

The ERTS-1 resolution is only marginally useful for NED purposes. Better spatial resolution approximating that of the SKYLAB S190B camera would significantly increase operational usefulness to the NED Reservoir Control Center, except perhaps for the monitoring of flood stages where ground truth data is practically a necessity.

4.2.6.4.2 Temporal Resolution

The 18-day ERTS-1 coverage is inadequate for the operational needs of the NED Reservoir Control Center. However, it is considered that an every day or every other day coverage would be significantly useful during high flood potential periods. If this were the case in order to conserve production costs and file space, it would be advantageous for NED to have the option as to how often the imaging cameras are "turned on" over its area of responsibility.

4.2.6.4.3 Spectral Resolution

The spectral resolution afforded by the ERTS 4-band MSS (0.5 to 1.1 micrometers) seems adequate for many operational concerns of NED. However, the experimental use of additional bandwidths, especially those in the ultraviolet and the thermal infrared might help solve some of the problems of quantifying certain feature characteristics on the imagery such as snow water content, water depth and water quality.

4.2.6.4.4 MSS Versus RBV Imagery

The 4-band MSS imagery was the major source of ERTS imagery available for study although a few early RBV frames were studied for comparison. For NED operational purposes, at this time, neither MSS nor RBV would have distinct relative advantages or disadvantages over the other. The RBV images have somewhat better geometric fidelity, a more convenient square format, intersections of latitude-longitude annotated on the image, and 3-bands ranging from 0.48 to 0.83 micrometers (which cuts off some of the near-IR). On the other hand, the MSS has better spectral fidelity, lesser geometric fidelity, a more inconvenient skewed

format, annotated marginal latitude-longitude tick marks, and a wider spectral range divided into 4-bands ranging from 0.5 to 1.1 micrometers in the near IR region.

4.2.6.4.5 100 x 100 Mile Format

The 100 x 100 nautical mile format of the ERTS imagery is satisfactory for NED purposes. Major tributary watersheds conveniently fit into one or two frames. However, the Connecticut River, with a length of 400 miles, would be best formatted using a long continuous strip produced by a single ERTS orbital pass from Canada to Long Island Sound. This long format would produce a true synoptic view of north/south trending rivers such as the Connecticut, rather than the pasted-together, butt-edged look of the present ERTS 100 x 100 mile format.

4.2.6.4.6 Side Overlap

The additional temporal information in the 39 to 52 mile side overlap in the New England latitudes produced by ERTS orbits 24 hours apart is not considered to be operationally useful for NED. These overlap strips produce the two views separated by 24 hours just once in every 18-day period -- and it is only fortuitous if the overlap strip occurs in a particular watershed of interest.

Overlapping pairs of imagery in the direction of ERTS flight produced by a framing camera such as the RBV might be useful for producing stereo effects for improving interpretation of vertical dimensions.

4.2.6.4.7 Sun Angle

The constant sun angle inherent in the ERTS imagery is a distinct advantage in interpretation of scenes in the NED region. This advantage is particularly apparent when compared with aerial imagery taken at different sun angles of mountainous terrain typical of the New England region.

The 1000 hours ERTS overflights seem to be advantageous for viewing New England terrain. A much earlier morning ERTS passage and/or a late afternoon passage (especially in winter) would produce greater terrain relief shadows but less illumination

causing greater interpretational difficulties.

NED operations are not geared to a particular single time of the day; hence the particular time of ERTS imaging is otherwise not important from the NED viewpoint. However, one could speculate about the future usefulness of synchronizing ERTS imaging with the observational times of the meteorological observations of the National Weather Service and other hydrometeorological data collection networks. Such synchronization of ERTS with other weather and water observations could become quite important as computerized forecasting techniques using mathematical models become more and more relied upon.

4.2.6.4.8 Factors Which Degrade Resolution

Factors which degrade the spatial, temporal or spectral resolution of ERTS imagery are of extreme importance to NED operations. Any degradation of the interpreted product, for whatever reason can severely reduce the usefulness of the imagery for NED reservoir control purposes.

For example, in our studies, interpretation of ERTS imagery has been compromised by weather factors such as cloud cover, haze, and atmospheric attenuation caused by light scattering.

Seasonal variation of sun angle provides distinct differences in interpretation of ERTS imagery for NED purposes. In winter, the lower sun angle increases terrain shadows which enhances observability of terrain relief features; however, this advantage is reduced by the lower level of scene illumination. On the other hand, the high angle of the summer sun provides less noticeable terrain relief but greater scene illumination.

The increased summer vegetative cover obscures ground features. In winter with loss of vegetative cover, terrain features are more easily interpretable, and rivers and smaller tributaries are more distinct (especially after a light snowfall covers the ground, but not water surfaces).

In general, the early spring ERTS imagery (April) yields the best overall scene interpretability because of high sun angle, good illumination, and sparse vegetative cover.

4.2.6.4.9 Need for All-Weather, Day-Night Capability

For NED operational purposes, an all-weather, day-night capability would greatly enhance the usefulness of the ERTS imagery. Major decisions are made during flood situations which occur during inclement weather and many times at night. Restriction of imagery capabilities to clear weather daylight hours imposes severe difficulties for NED operational missions. The use of thermal infrared bands as well as radar should be considered in attempting an answer to these needs.

4.2.6.4.10 Timeliness of Receipt of Imagery

The day-to-day operational requirements of NED demand timeliness of hydrometeorological information. The usefulness of ERTS imagery is severely reduced as the time-lag of the data increases. For example, receipt of the ERTS imagery 1 to 5 months after the overflight occurs renders the imagery useless for operational purposes. Real time receipt at the NED Reservoir Control Center as mentioned in section 4.2.6.3 would be ideal. However, a 1 to 2 day delay of receipt of imagery could still be useful for certain operational purposes such as some water quality, ice, snow and soil moisture depictions. Longer delays would be acceptable for long range water quality, post flood and other similar studies.

4.2.6.4.11 Reliability of Regular Receipt of Unimpaired ERTS Imagery

NED must depend on reliable receipt of data for operational purposes. Failure to routinely receive unimpaired ERTS imagery for any reason (e.g., due to breakdown in data processing, excessive cloud cover, etc.) would: (a) jeopardize operational functions, (b) lower the reliance on the ERTS imagery on the part of operational personnel, and (c) in the absence of backup data for ERTS imagery, require special ad hoc operational procedures to be implemented (perhaps at greater cost and yielding reduced information to the Reservoir Control Center).

5.0 A LOOK INTO THE FUTURE

This investigation of the separate and coordinated uses of the ERTS-1 Data Collection and Imaging Systems has been

part of an overall Corps of Engineers R & D program to assess potential remote sensing capabilities for operational watershed management purposes. Since this study has indicated technological feasibility, albeit with the expectation of further advances in imaging systems and products, we feel that an immediate entry into the next stage of development is appropriate. This calls for pilot project test and evaluation demonstrations under quasi-operational conditions. At this stage, practical operational factors and economic feasibility will be tested. This is the express purpose of our ERTS-B follow-on investigation which will heavily emphasize development of an interactive computer processing system for depicting hydrologic data from ERTS imagery. It is also the goal of our related construction of an inexpensive, semi-automatic and easily maintained ground receive station for direct real time acquisition of ERTS DCS data. If these demonstration projects are considered successful, steps leading toward full implementation of an operating system will be recommended.

In summary, we feel, that this opportunity to participate in the ERTS-1 experiment has significantly contributed to the ability of the Corps of Engineers to keep pace with the advancing technology applicable to watershed management. It is through the generosity and cooperation of agencies such as NASA that the operational arms of the Federal Government can seek new and improved means of meeting their increasingly complex goals.

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